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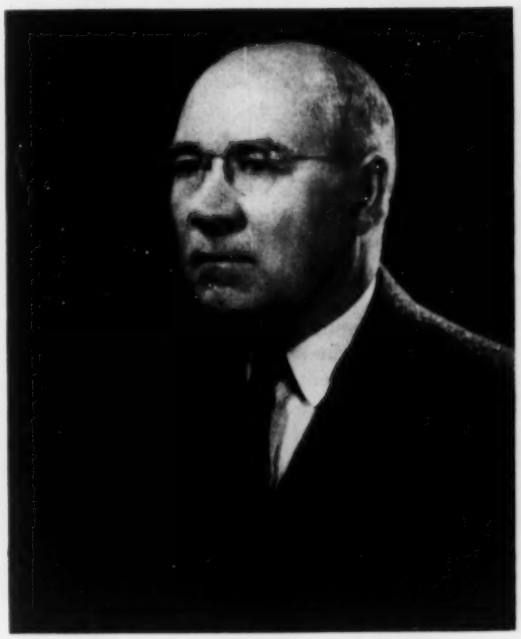
PRESIDENT'S MESSAGE



The New Outlook*

By Howard P. Emerson

President, American Institute of Industrial Engineers, Inc.

The past year has brought the American Institute of Industrial Engineers to a new level of achievement and growth. Our growing pains are over. We are now a mature organization which is going places. I should like to cite a few evidences of this maturity.

Evidences of Maturity

1. Our organization covers the whole United States. It is divided into six geographic regions with 6 to 13 chapters each, 59 in total at convention time, all actively contributing to AIIE growth.

2. We have a central office with a business administrator, who has improved communications with regions, local chapters, committees, and officers.

3. The growth of AIIE has been healthy:

		Student Members	Associate & Senior Members
100 members (including students) in 1948			
4100	1955	1000	3100
over 5100	1956	1300	3800

(These figures do not include 250 affiliate members, i.e., those associated with us from other related professions or those who do not yet have the necessary experience for full membership.)

4. Outstanding men in the profession are joining AIIE, as those in the Membership Qualifications Committee, who last year reviewed over 1100 applications for membership, can testify.

5. During the past year research responsibilities have been assumed. This was a significant and important step, for without it we could not claim maturity as a profession. Universities, industrial concerns, and the government agencies now expanding Industrial Engineering work, all will be doing research. AIIE has a unique place in further stimulating research and in disseminating and promoting application of its results.

6. The Journal of Industrial Engineering is now a reference source. Its pages and the caliber of the articles published in it reflect the maturity of our organization.

7. Finally, we now have an official definition.

The New Definition

This new definition was developed last Fall at Cornell under the auspices of the Long Range Planning Committee. A dozen previous definitions were drawn on. It was adopted by the Board of Trustees of AIIE in October, 1955 for use in the Opportunities Brochure, and approved by the 1956 Convention for general use.

You have seen copies of the definition in the Journal of Industrial Engineering. You can buy copies of it for framing. It appears in the new brochure on Industrial Engineering opportunities.

I think we were wise not to define our field too soon. In a rapidly growing profession too early setting of a definition might have erected a barrier to its fullest development. This might have been fatal. But some recent developments make it almost imperative that we define ourselves.

* Excerpts from an address to the 7th Annual Convention of AIIE, Washington, D. C., May 19, 1956.

Need for Definition

To quote an editorial from Factory magazine for May 1955:

"The ranks of industrial engineers are steadily growing. As manufacturing gets to be increasingly complicated business, you can expect further growth. You can also expect growing confusion unless somebody comes up with a good, accurate answer to the question: 'What is an industrial engineer—and what does he do?'"

A look at this year's conference program also illustrates the need for a new definition. The program was divided into three types of topics. But only two sessions were on traditional fundamentals. Two sessions were on current practices. But eight sessions were on topics never mentioned in I.E. conventions 5 years ago. Some of these developments, started outside Industrial Engineering, are invading industry and fields of the Industrial Engineer. Thus they can be threats to our profession. But they can also be converted into opportunities and a "new outlook" for Industrial Engineering.

Three of them in particular cause need for a change in scope of Industrial Engineering and its definition. These are:

1. Modern statistical analysis applied in industry
2. Operations Research
3. Automation

Until these appeared we were "rocking and rolling" along without a new idea since the days of Frederick Taylor and the Gilbreths, 40 years ago. (Job Evaluation was the only major concept which pioneers in Scientific Management did not have in mind, until these three developments came along.)

Each of these fields was a war development, like other technical advances growing out of war-time necessity. But each has continued with its own separate organization and separate publications.

Such separate intensive development of new techniques, while a threat to established procedures, nevertheless, has its uses:

a. To train plant men who did not get training in these fields in engineering college (perhaps due to blindness of faculty or lag in recognition of the need).

b. To develop the new field more intensively by research and by bringing together those with a strong mutual interest and enthusiasm.

These purposes are still needed although the I.E. graduate of the future may come out of college with training in all of them, as new tools of the Industrial Engineer.

By absorbing these new developments into Industrial Engineering or by encouraging Industrial Engineers to take active part in them, we can convert threats into opportunities. We have already done this with Industrial Statistics. Let's see how it was done.

1. *Statistics*

War-time requirements for control of quality and quick ways to inspect products forced an examination of statistical methods. Engineers like Eugene Grant investigated these methods, picked out some applicable in industry, and prepared courses and texts to explain their use.

To-day 50% of accredited I.E. curricula contain quality control or statistics courses. We have gone further than this. We use statistical methods to analyze I.E. time study data and plan plant experiments. Studies of operating delays by random probability techniques have led to making time studies on some types of jobs by sampling of work, instead of with stop watches. A new text by Ralph Barnes on *Work Sampling* now supplements his classic text on *Motion and Time Study*.

Thus we have absorbed and put statistics to use. A threat becomes an asset.

2. *Operations Research*

Can we do the same thing with Operations Research? The Industrial Engineer should have invented Industrial Operations Research. The reason he didn't is "sub-optimization."

Sub-optimization is a fault not only of industrial but of other engineers who concentrate on details instead of over-all objectives and functions.

How can we avoid sub-optimization and capture the Operations Research over-all point of view? The I.E. may never try to make an over-all equation for a plant, but in starting a problem and when he has his solution he can lift his eyes to the over-all view and check against broader objectives.

Operations Research uses probability theory. (The I.E. already uses this.) Operations Research uses "linear programming." (Interpretations of linear and matrix algebra concepts are needed such as Eugene Grant worked out for statistics. Such interpretations are under way. Our JOURNAL has kept you informed about them.)

Another characteristic of Operations Research is the team approach. The I.E. is well fitted to be the coordinator of such a team if he prepares for it and aims high enough.

3. *Automation* (threat or opportunity) Again the I.E. should have invented this development.

However, automation eliminates manual labor and need for time studies thereof. Feed back and automatic adjustments before bad product is made eliminate need for the quality control chart; electronic measurements of each and every product eliminate need for sampling and sampling plans. What then becomes of Industrial Engineering?

Again, threat can become opportunity. Industrial Engineering can be expanded:

a. To redesign product and whole process for automation.

b. To analyze the plant as a system of redesign it to incorporate automatic controls. (Let the M.E. design the automatic machines and the E.E. the automatic controls.)

c. To adopt the over-all point of view.

d. If automation and use of computing equipment are to be successful, the I.E. is needed to design the right methods to be automated or recorded.

e. The I.E. also needs to use computers on his own work of design and analysis. (An analogue computor for example can be designed to show over-all profit from percentage savings in manufacturing costs.)

Opportunities Instead of Threats

Is the Industrial Engineer converting automation and Operations Research into opportunities instead of threats as he did with statistical quality control? To quote again from the Factory Editorial:

"Right now you'll find as many industrial engineers in the middle of automation activities as you will machine designers and control engineers—and as many in the new fields of operations research and linear programming as professional mathematicians."

As a further step, it is important that a definition of Industrial Engineering incorporate these new developments if they are to be opportunities under Industrial Engineering instead of threats from without.

The new definition of Industrial Engineering does exactly this. It also encompasses the variety of Industrial Engineering functions into one over-all concept. I'd like to discuss key words in the new definition in relation to the new scope they give to Industrial Engineering.

Design

The I.E. designs jigs and fixtures, work place, and improved layouts. Why not the whole plant? Who better can determine capacity, plan flow of work and organization. Predetermined time standards now provide data for design of layout in the engineering office. Why be content designing jigs and fixtures?

Systems

An important new way of looking at old phenomena. With its concepts of input and output, mechanism or process operating under laws or standards, and the idea of feeding back records of deviations from standards to correct or adjust input, it lends itself to fuller use by the Industrial Engineer. Man will still be a link in all but narrowly restricted systems of production, although his role may change. The systems can be a production line, department, plant, or *complete industrial enterprise*. Walter Rautenstrauch's concept of the Design of Manufacturing Enterprises is still important although his book of that title is out of print. Like our new definition, his concept of the Industrial Engineer is large in scope.

Social Sciences

Who but the I.E. can apply social sciences to production and bring the social scientist into the management team. The I.E. knows all concerned: mathematician, physical or social scientist, manager and worker.

Engineering Analysis

What we have a shortage of. It has proven to be a most valuable commodity in war or peace in a technical civilization. Employers pay exorbitant salaries to graduates having training in engineering methods of analysis and design, and nothing else.

Specify, Predict, and Evaluate

Would the authors of the definition let us substitute better known I.E. words when we try to visualize these terms? *Set standards* for specify. *Estimate* for predict. *Check* or *audit* for evaluate.

There we have it—the new definition of Industrial Engineering. It is still a staff rather than line responsibility. It still covers functions which preferably should be grouped in an I.E. department but functions which also find other places or outlets in an industrial organization.

This definition converts threats into opportunities by encompassing the new developments, making them part of our field or us part of them. It thus enlarges the profession, and attempts to show wherein it is unique.

Feet on Ground

But let's keep our feet on the ground. It is still true that a good solid job of Industrial Engineering can consist in using conventional methods for:

a. Work measurement, setting standards for quantity, quality and cost
b. Layout and materials handling
c. Safety
d. Scheduling, routing and dispatching
e. Decisions between alternatives
f. Organization, description and evaluation of jobs

We don't need complexity for the sake of complexity. Many new manufacturing companies, government agencies, foreign companies, and merchandizing firms are just beginning to apply conventional Industrial Engineering techniques.

There is room in AIIE for both the time study man (if well grounded in methods work) and those engineers working in operations research or automation.

So in using our new definition let us not get too far from our traditional functions, let us keep our feet on the ground as we examine the new vistas and scope of our profession.

In the year ahead AIIE can help bring Industrial Engineers closer together; through our committees and the Journal we can bring greater cohesion, unity, and interrelationship between our many available techniques. The real definition of Industrial Engineering after all is in what we as Industrial Engineers do and the achievements we record.

A Continuation of the Best in Industrial Engineering

By George P. Champion

Senior Operations Research Analyst, Lockheed Aircraft Corp.

In February of this year an article in FORTUNE Magazine (19) said, "Operations Research is an applied science, or perhaps a branch of engineering . . . some predict that the name Operations Research will fade out, while its proved virtues will be absorbed into industrial engineering." If this should become true, it would be because operations research is a continuation of the best in Industrial Engineering. Let's see why this is so.

Within recent years Johns Hopkins, Columbia, Georgia Tech, and Cornell (among about two dozen other universities) have made Operations Research an accepted 'field' within Industrial Engineering. "This approach would appear to argue that Operations Research is an expansion of a new direction for industrial engineering," says Joseph McCloskey, (11) a leading operations research writer, "and it will strengthen the hand of the industrial engineer as he expands his offerings to management." "All in all," stated an article in *Factory Management and Maintenance*, (12) "operations research is really a sharper kind of industrial engineering."

Several years ago Cyril Hermann and John Magee wrote in the *Harvard Business Review* (5) that, "perhaps the most difficult distinction to make is that between operations research and modern industrial engineering. The pioneers in the field of industrial engineering did work of a character which operations research analysts would be proud to claim for their field." With this being so, let's take a look at how the best of one field is found in the other.

WHAT It Is

If you enjoy solving puzzles, working on committees, and being able to tell others that A is about twice as good, or bad, as B, then you should enjoy Operations Research. And if you have problems and need to know whether A or B is better, and if so, about how much so, then you will be grateful if you have Operations Research to help you.

Assuming you have problems, and perhaps they are industrial engineering problems, then what is this thing, Operations Research (or "opsearch," or "O.R." as many call it), that will be such a help in solving them? Most people agree with Dr. Charles Kittel (9) of Bell Laboratories in saying that it is, "a *scientific method* for studying the operations of large, complex organizations or activities in order to provide *executive* departments with a *quantitative basis* for *making decisions* that will increase the effectiveness of such organizations." Others say it is, "the scientific analysis of problems involving any form of action in order to make that action more efficient." Earl Lamm (10) of Mulligan Company defines it as "the application of the scientific method to problems outside of the conventional fields of science." *The Johns Hopkins Magazine* (7) calls it, "a new and mysterious science." David Parker (15) of the military says it is, "our greatest secret weapon." Russell Ackoff (1) at Case says it is not new, not mysterious, not secret, not a weapon—but it is a science. Professor Zuckerman (22) in England agreed that it is not a new thing, and that it is nothing more than the application of ordinary scientific methods of thought, or controlled commonsense, to the analysis of complicated and dynamic problems.

It has been said that, "Typical O.R. subjects involve the repetitive operations of large numbers of men and machines." So, of course, does industrial engineering. Morley Melden of *Factory Magazine* feels that it is "the extension of the best industrial engineering practice to include more advanced mathematical techniques." Young engineers call it "ivory tower stuff." My company agrees with Dr. George S. Pettee of Johns Hopkins that "Operations Research is a profession." Others say, "the application of the scientific attitude and the associated techniques to the study of operations, whether business, government, or military, is what is meant by operations research." "Quantitative horse sense" is a brief, and good, definition.

WHO Is Involved

In his final report to the President, Fleet Admiral Ernest J. King had these words to say on the usefulness of O.R. to the United States Navy, "Operations research, bringing scientists in to analyze the technical import of the fluctuations between measure and counter-measure, made it possible to speed up our reaction rate in several critical cases. The knowledge resulting from continued cross-check of theory with practice made it possible to work out improvements in tactics which sometimes increased the effectiveness of weapons by factors of three or five, to detect changes in the enemy's tactics in time to counter them before they became dangerous, and to calculate force requirements for future operations."

Just five years back, it was estimated by Herbert Solow

in *Fortune* (18) that there were then about 250 O.R. professionals in the U. S. A total of a half-a-dozen aircraft companies today employ that many. At that time Sears Roebuck, Simplex Wire & Cable, and Republic Steel were among the few industries using O.R. consultant services to advantage; and six other firms were listed as being among other sizable companies investigating O.R. Today, almost all large organizations have an O.R. department in one form or another. Writing in *Fortune* (19) this year, Mr. Solow lists 70 large firms as buyers of O.R.; in the fields of communications, electrical, foods, mining—metals, motors—parts, machine tools—machinery, petroleum—chemicals—pharmaceuticals, retail—mail order, textiles, and transportation; and writes, "Today a full list of current and recent O.R. customers would be too long to publish."

Now, what makes an O.R. man? If he is basically an industrial engineer, he is one who has developed to an intense degree his special training in experimental observation and ability to draw a valid conclusion from a limited amount of data. He is more interested in the researcher's 'why' than in the engineer's 'how.' He has extended his training in "the essentials of probability and statistical theory, and is able to deploy refined and potent numerical techniques."

The British Committee on Industrial Productivity (2) has listed five qualities required in an operations research worker:

1—he must have had training in the scientific method in some field.

2—he should have a specialist's knowledge in this field, and be able to cooperate and integrate the work of other specialists.

3—he must have interest in the application of his work.

4—he should have a high degree of general intelligence.

5—he should have a knowledge of the practice of operations research.

The first four could well describe the requirements of an industrial engineer. A continuation of these qualities by adding the fifth gives us our O.R. man.

WHEN There Is a Difference

A difference between the industrial engineer, as such, and the strictly O.R. man, would be that the O.R. man, unlike the industrial engineer (or management consultant), makes no decisions. This is the job the executive should do. The O.R. specialist is looking primarily for answers that can be expressed in numbers, and when he has turned over his quantitative conclusions to the executive, it is then time for the O.R. man to seek a new problem to be solved. This is basic—for not having to make the decision allows the O.R. specialist to arrive at the basic numerical data impersonally and accurately.

A further distinction is made by Hermann and Magee (5) when they say that, "in modern practice, industrial engineers usually apply established methodologies to their problems. Moreover, their work is generally restricted in scope to manufacturing activities and, in some cases, to distribution operations." Their thought is that O.R. often applies new and sometimes yet unproved methodologies, and does not restrict itself primarily to manufacturing and distribution. They continue by saying, "Equally important, industrial engineering is not commonly characterized by the mental discipline and techniques of analysis that are commonly associated with the physical scientist; operations research is." (There may be some IEs who take exception to this!)

That there may be difficulty in defining exactly where operations research is different from other fields can be readily seen when we find that the terms operations research, operations engineering, operational analysis, operations analysis, systems analysis, systems evaluation, operations evaluation, and applied statistics have all been used as being synonymous with operations research.

WHERE Does It Work

O.R. has shown real usefulness in extending management's ability to cope with complex problems. As proof, Arthur D. Little, Inc. of Cambridge, Massachusetts gives numerous examples in their *O. R. Case Histories* of studies that have been carried out to useful conclusions. These have included (a) establishment of an equitable bonus system, (b) the best distribution of products among manufacturing plants and warehouse locations, (c) an accurate measure of annual clerical costs of potential buyers from just their annual statements, (d) a practical evaluation of equipment design during early development, (e) the construction of a new and better method of directing promotional salesmen to appropriate accounts, (f) evaluating trade advertising, (g) anticipating the correct practices to convert new policies into minimum-cost production schedules, (h) finding the relationship of selling cost to manufacturing activity for greatest profit, and (i) the establishment of sound inventory policies in the face of business fluctuations.

These uses may not be as dramatic as those told by Herbert Yahraes, (21) and Edward and David Parker, (16) where B-29's were the best planes for close support of ground troops in Korea, and that napalm was the best tank killer, that a mine blockade of Japan in World War II would about stop Japanese ocean shipping (which it did); but the industrial uses should be of more interest to industrial engineers and executives. The British first used O.R. effectively, beginning in the military field. They then extended it to the social field, into the Royal Ordnance Factories, cotton mills, transportation, foreign trade, as well as brick making and road building.

We in the United States have applied it to information handling for inventory control, to agriculture (growing peas, snap beans, sweet corn, lima beans, spinach), for job classification to guarantee the most equitable compensation, in underground mining, in determining the product mix that would result in the greatest profit, to find the warehousing schedule that would minimize freight costs, in auditing, and among others, a rational basis for distributing advertising and promotional effort.

It is also most interesting to see the scope of the different problems that O.R. can handle. Borrowing an analogy from military terms, we can call them technical, tactical, and strategic. Arthur Brown of A. D. Little, Inc. gives some very good examples of the kind of work that has been done at each level: (3)

On the technical level:

A study of factors affecting open-hearth furnace output;

A study of the distribution of work-load on a number of sorting and loading cranes.

On the tactical level:

A study of the profit which a certain store might gain from remaining open one evening in the middle of the week;

Study of traffic accident rate as a function of the local factors governing traffic.

Under the strategic level:

Studies in sales forecasting, and in estimating requirements for new services;

And a study of the effect of price on passenger receipts of a certain railroad.

HOW It Operates

The majority of those interested seem to be in agreement that operations research is (a) a staff function to (b) help the decision maker guess right more than 51% of the time by (c) using the scientific method to (d) reduce a problem and answer to a usually numerical value.

Now, there are many ways to approach the "scientific method" of studying problems by (and this is important) *research* methods. Russell Ackoff (1) has submitted the thought that "the concern of the operations analyst with producing measurable efficient solutions to problems has resulted in the formation of principles of research procedure whose function is to assure efficient research. We may consider five such principles of operations research:"

The Principle of Measurement. Wherever possible measure the properties of all variables that count and the relationships between them. Where measurement is not possible, make it possible.

The Operational Principle. Take into account not only the decision maker but all those who carry out the decision and are affected by it. Include also the instruments and environments involved in the operations. Consider these not in terms of a fixed set of properties, but in terms of how they change over time.

The Feed-Back Principle. Do not end the research with the selection of a proposed solution. Evaluate the proposal in action. Where it is not good enough, conduct further research. This involves a continuous interaction between all phases of the research and operations, and continuous communication between all parties involved.

The Cooperative Principle. Include on the research team representatives from as many areas of science as possible. Even include representatives of areas which do not appear to be directly involved with any aspect of the problem.

The Practical Principle. Evaluate every phase of the research relative to the research objectives. This requires an explicit formulation of the objectives of the decision maker and all those to be affected by his decision . . . the decision maker and those affected by his decision can be considered to be consumers of O.R.; the decision maker (or policy maker) is the *immediate* consumer, those who carry out the decision are the *intermediate* consumers, and those who ultimately consume or are affected by the services and products provided, are the *ultimate* consumers.

Morley Melden (12) separates the O.R. approach to problem-solving into four features:

1. A firm conviction that intangible factors can be related. No variables are really intangible. It's just that you've had to call them intangible because their effects were not obvious, or could not be easily evaluated.
2. A team combining their experience. Operations researchers adding their skill in science and mathematics to industrial experience.
3. A scientific procedure for problem-solving:
   (a) Orientation—defining the problem.
   (b) Gathering data on factors affecting results.
   (c) Analysis of data—using mathematical tools.
   (d) Developing a formula, or plan.
   (e) Testing the plan on a sample problem.
   (f) Developing working tools—simple procedures which the workers can use, which should give results similar to the formulas.
4. A great many 'tools' to work with.

TOOLS

The first two 'tools,' and the most important, are *commonsense* and *judgement*. Added to these are calculators, calculus, differential equations, econometrics, general mathematics and computer theory, geometry, nomograms normal curve tables, optimization theory, Poisson tables, probability theory, statistics, random numbers, and other mathematical tools such as the following:

Standard Industrial Engineering Methods

Here we are indeed on familiar ground. O. R. uses all the tried and proved industrial engineering tools like methods improvement and analysis, ratio delay, statistical quality control, time-and-motion study, work measurement, sampling, and simplification. The industrial engineer thus makes an excellent member of the O.R. group, since he carries to its research a continuation of the best tools of his field.

Game Theory

This is a science based on the rules of probability—and identified with AEC Commissioner John von Neumann and Princeton economist Oskar Morgenstern. This is a mathematical theory that selects the best way to play against an opponent who has a strategy of his own so as to minimize your chances of losing. It offers some useful rules for outguessing competition in business situations.

Information Theory

Those using electronic systems for handling paper work are interested in theories which are appropriate in determining the amount of coded information a system can handle. Fitting this requirement are formulas which have been developed by people in the communications field to determine the amount of information that can be sent over transmission lines. In some cases the measure of effectiveness (M.O.E.) of plant operations can be found by applying this theory.

Linear Programming

The Air Force set out throught Project Swoop to demonstrate quantitatively the dependence of various industries on one another. This work has been called Input-Output Analysis. Linear programming is an outgrowth of this, and goes beyond it by trying to relate the different variables in some optimum way—such as profit maximization or cost minimization, and can be used to solve problems where many variables have to be related.

Once the problem has been defined, and you have put some satisfactory limits on it, the factors that are to be programmed are translated into mathematical symbols from which are derived systems of linear equations and inequalities. When formed into tables and manipulated algebraically, all possible solutions can be compared simultaneously to maximize or minimize the optimal results desired. John J. Wilkinson has a very good article on this in the Vol. VII, No. 1, January–February 1956 issue of the JOURNAL OF INDUSTRIAL ENGINEERING.

Modelmaking

These models are conceptual, rather than physical. They may use the method of symbolic logic in dealing with systems that include people as well as machines, materials, and dollars. It is a cross between intuitive judgment and logical analysis, using mathematical analogies by describing in the shorthand notations of mathematics how a system behaves.

Most of the written "natural laws" are conceptual models; and this tool is borrowed from the physical sciences. With it O.R. can make models of operational systems which might not yet exist, and by subjecting them to additions, integrations, subtractions, can determine the effects of proposed changes on the system.

A variation of this latter technique is Operational Gaming, an adaptation of war gaming to business. This is sometimes called Simulation, for the effect of possible solutions of various external factors is simulated to find the solution best fitted to the result desired.

Monte Carlo Techniques

At times we are confronted with a problem which needs a numerical answer, but has so many similar groups of data that it is extremely difficult to approach an answer by the usual rigorous mathematical procedures. In this case we can use the Monte Carlo technique of performing simple calculations over and over again in a random way, or taking random samplings many times from our basic data. By this method we can get closer and closer to the right answer in a relatively short time.

Servo Theory

Very often it is desired to maintain a specific relationship between one variable and another. To do this the variable you wish to control is compared with the other one, and the information on any differences is fed back into the control system, which then acts to control future operations by bringing the first variable back in line to achieve the fixed objective.

This is also known as the automatic feedback principle. A servomechanism (such as a thermostat) is used to control mechanical systems. In O.R. this concept is applied to mathematical models to analyze business measurements.

Symbolic Logic

This tool would be expected to be most useful in the beginning of an analysis of an operation, and is a preface to it. It normally uses letters or symbols to describe the relations or restrictions of a real situation, using intuitive, generalized reasoning and analysis to set up the symbols. It is possible to use high-speed computing machines in the "algebraic solution" of these symbolic expressions which are unmathematical in nature—provided that when evaluating the results obtained, full recognition is given of the logical restrictions that were originally placed on the variables.

Waiting Line (Queueing) Theory

When delays at servicing points (or bottlenecks) appear, we have a problem where waiting line theory, based on the use of the laws of probability, will help us determine the correct amount of effort to expend to correct the delay. These delays, in the form of idle labor, machine downtime, unattended customers, are always costly. However it is usually more costly to try to abolish *all* delay. By dealing with the waiting-line concept mathematically, we are able to determine the most economical way to relate the capacity of the proposed equipment to the number of units that are waiting to use the equipment. D. G. Malcolm has an excellent article on this subject in the Vol. VI, No. 6, November–December 1955 issue of the JOURNAL OF INDUSTRIAL ENGINEERING.

TERMS

In each separate field, the terms which are widely used are a part of the tools of that field. Some of the following may be common to both I.E. and O.R.—but all are part of the new language of O.R.:

One of the first you will hear in O.R. is, "What is the M.O.E.?" or *Measure Of Effectiveness*. This is a yardstick that combines the important units with which we are working (say, functional performance and company effort) into one analytical expression. It allows us to evaluate how effective our solution will be.

Optimization is deciding what is the correct thing to do with each of several variables that are a part of the problem, in order to maximize or minimize the desired result—but not necessarily the variables themselves.

Minimax is attacking the problem in such a manner as to soften the blow of a wrong solution, by minimizing the maximum possible damaging effect.

Setting up a *Frame Of Reference* is necessary to make sure we are all thinking in the same terms, about the same

thing. It gives us a point of departure, and a mathematical base from which our values can be taken.

The *Parameters* are the units with which operations research works. They are the variables or influences which affect the operations or the process.

Any situation that is made up of random events which are uncontrollable and thus uncertain is said to be *Probabilistic*. If there are intangibles involved, and we place numbers on them, we have *Quantified* them. We then try to find a *Correlation*—a measure (between zero and one) of the dependence of one variable on another due to a direct relationship involved (one), or all due to chance and thus no relationship (zero).

We introduce *Regression* when we measure not only correlation, but the effect of one variable on another. Studies to show inter-industry dependencies have used regression to show the *Input-Output* relationship of several factors to each other. We have a *Stochastic* process when the element of time is introduced into the random variables we are working with.

We have a *System* when we have a group of men and the tools they use to perform some determinative function; that is; a group of human beings using machines to amplify their capabilities—a man-machine group.

To the above tools, Edward Varnum (20) of Barber-Colman Company would add two more—*imagination* and *tact*. It is not suprising that these two factors are emphasized by many writers in O.R., both here, in Canada, and in England. Both the successful Industrial Engineer and the O.R. man may have imagination. On the other hand, many believe that tact is most desirable in the former, but mandatory in the latter.

OTHER Characteristics

So much for tools and terms. Joseph McCloskey (11) believes that, "actually, there are two characteristics of operations research, neither of which have much to do with technique, that serve to distinguish it from the other management sciences. These are the 'Whole-System Approach' and the 'Use of Mixed Teams.' . . . The whole-system approach is one that attempts an analysis of whole and sometimes very large and complex—organizations and systems, and makes no effort to compete directly with those who have specialized in the analysis of specific operations, such as production, sales, accounting, purchasing, or investment."

The mixed team concept is of course the bringing of "multidisciplines" to the problem. Where one man is capable of doing this, he might be considered the mixed team; yet even this rare individual can profit by teaming with others who are proficient in fields in which he is not a master—and the O.R. mixed team concept requires this.

The Committee on Operations Research of the National Research Council has stated that "the two principal things that make operations research an essentially new field are 1. its inclusiveness: dealing with problems that are organization wide, and dealing with the *whole* of such problems, and 2. its direct relation to management: having unimpeded access to information, having direct cognizance of over-all problems, and having direct relations with the policy-determining and decision-making levels."

"The novelty in operations research," says A. A. Brown (3) in summing up this thinking, "lies in placing persons capable of scientific research at the proper points in the organizational structure, with wide terms of reference and with wide freedom to investigate."

WHY It Works

William Fair (4) of Stanford tell us that "an approach to the problem of the firm can be made from several directions, preference usually being dictated by the background of the would-be approacher. The business school's subdivision of the whole into subproblems, the economist's marignal analysis, the mathematician's linear programming, and the so-called 'practical' businessman's 'judgement' all represent apparently different efforts to achieve a common end." So also is the effort of the physical scientist and engineer's operations research.

Philip Morse (13) of M.I.T. gives us the comparison between "the civil engineer using mathematics and physics in designing or strengthening a bridge, and the operations research worker using mathematics and other sciences to study and improve the interactions in an organization of men and equipment while it is performing some cooperative task. The civil engineer reports to and works closely with the builder of the bridge; the operations research worker reports to and works closely with the administrator, the executive officer in charge of the operation." And, he does it as a staff member, leaving up to the administrator the decision as to whether his recommendations will be followed.

Another thing that distinguishes O.R. in its method of working is that it is concerned largely with improving the use of presently existing things, more than with the developing of new ones. Many of the successful O.R. applications in the past have been made in greatly increasing the efficiency of *existing* tools, practices and systems—development being left to the development research people. As *Fortune* has said, "O.R. does not try to provide new gadgets, but rather improve ways of using those already available."

William Horvath (6) of the Operations Evaluation Group sums it up for us when he says, "the sole function of the operations research staff is to increase the understanding of the administrator as to the implications of the decisions which he may make. . . . The problems occurring in the industrial and governmental fields will fit into one of three categories; technical—the performance of machines, tactical—the best use of machines by men assigned to them (not to be confused with time and motion studies or other systems research) and strategical—the optimum division of effort in different lines of activity."

But even here, a word of caution. Ellis A. Johnson (8)

of the Operations Research Office tells us that, "Military operations research is no longer concerned merely with problems of achieving optimum results with existing systems and equipment, which was all that most wartime operations research could hope to do. It now develops predictions of the results that may be expected from adopting proposed courses of action; these predictions can then be used as guides to the development of future strategies, tactics, and weapons." The same holds true for industrial operations research.

AND Finally

Operations Research certainly has a place in any large organization. However, a word to the too eager O.R.er or the too expectant executive. The early days of O.R. were periods of glamorous and spectacular successes. However, when the O.R. groups began to expand out of their original fields of inquiry (Air Force radar, Navy anti-submarine, and Army anti-aircraft problems) their efforts became less productive as they tried to invade fields (such as infantry) which had been worked on for many years.

Omond Solandt (17) of the Defense Research Board of Canada gives an excellent example when he relates "the case of some enthusiastic Physiologist who just before the last war did a comprehensive study of hand tools, seeking to improve them. His paper on screwdrivers, which was very voluminous and contained many measurements, concluded that the best handle for a screwdriver was a simple cylinder. If you wanted to, you could make some grooves in the cylinder to improve your grip. . . . This seems to be a good example of what happens when you try to do research on a bit of equipment which has been very slowly developed over the years. It is much easier to produce spectacular improvements either in new equipment or in the use of equipment in new situations."

Let us here again accept a word of caution, offered by the British Committee on Industrial Productivity, and worth our recognition:

> First, Operations Research is still fairly new, and can make mistakes as well as solve problems. Its past achievements encourage its use in a wide potential field of usefulness. "Big improvements often come from the first quick survey of the new field." Second, it is complementary to and needs the results of research in the social, economic, scientific or technological fields—and in no way supersedes research in these fields. Third, O.R. is not a substitute for planning, and does *not* dispense with the experience and judgment required by the executive.

However, operations research is a continuation of the best in industrial engineering because, as Philip Morse and George Kimball (14) reiterate in their "Bible" of O.R., Operations Research is a *scientific method* of providing *administrators* with *quantitative information* for *making decisions.*

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An Industrial Engineer Looks at Automation*

By Stephen Arthur Derry†

Registered Professional Industrial Engineer

The 1956 technical world's cliche is the word "Automation". There is no doubt that the term will stay with us indefinitely. The towering interest in automation demonstrated by scientists, engineers, educators, technicians, press, radio, TV, economists, management and labor portrays the almost universal desire of our rising generation to accomplish the maximum result with a minimum effort.

The need for a more critical analysis of the meaning of automation is now a must. In current technical journals, periodicals, newspapers, advertising phrases and labor union publications, one can read all about the meaning of automation and its implications, but each writer has his own particular concept of its meaning. The various definitions have caused the term to be applied very loosely. This accounts for the apparent confusion of its true technical meaning.

The confusion which currently exists has caused labor union leaders to seize the word and mushroom it into a full scale Congressional investigation. (1) The leaders of the "International Confederation of Free Trade Unions" have ballooned the alleged fears that the expanding application of automation plays havoc with employment unless proper and timely corrective measures are taken. With this as the basis for a plea, the confederation has officially requested through proper channels that the United Nations Economic and Social Council place the problem on its agenda for the session opening in Geneva in July 1956. The federation seeks a comprehensive study of the economic and social repercussions to be anticipated. The plea further reflects the conviction of the confederation that the historic stagnation of employment associated with the so-called industrial revolution of more than a century ago may be impending.

Unequivocally documented facts are available that would prove beyond any question of doubt that these fears are the result of the misunderstanding of the term automation.

* This paper is abstracted from addresses delivered before AIIE Chapters in Knoxville, Tennessee (January 26, 1956); Winston Salem, N. C. (October 25, 1955); Columbus, Ohio (February 25, 1955); Cincinnati, Ohio (November 17, 1954); and lectures delivered before graduate industrial engineering class (Automatic Processes), North Carolina State College, Raleigh, N. C. (April-May 1956).

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Measuring Automation

Before one can devise a tool for the measurement of automation application, one must know the areas of manufacturing principles. Production of goods and services by automated methods is a natural growth development of manufacturing mechanization. Fig. 1 illustrates the facets of manual, mechanized, automatic and automated manufacturing. These areas exist side by side in practically every industry. Historically, this existence can be traced as far back as 1661, when a worker in Danzig, Poland designed a ribbon loom which worked continuously day and night. This loom could make six ribbons at one time. The local government promptly banned the use of this automatic loom because it would put workers out of work. Later, this daring inventor, who tried to lessen man's physical burden, paid the extreme penalty. He was publicly drowned by his fellow workers. (2)

Perhaps a closer examination of the records would reveal many similar instances where men paid the maximum penalty for their efforts in promoting improved manufacturing methods through the creativeness of their labor-saving devices, which in turn would have lessened man's physical burdens and at the same time produced more and better goods.

Automation is merely a clarification of manufacturing operations. In the manual area, physical effort is at its maximum, and the use of tools is at a minimum, that is, in quantity and value of the tools which are used in manufacturing by manual methods. The quantity of production is generally either a unit or a low volume group. Consequently, the finished product cost per unit is high. In the mechanized area, the manual labor has been considerably reduced through the use of power-driven machines with varying degrees of controls. These machines will perform one or more operations on a work piece with lowered effort on the part of the man who operates the power-driven machine. In this area, the labor force has been substantially upgraded, because skilled specialists are required to operate and maintain these power-driven machines. New jobs have been created and the work spread into new industries. Here manufacturing plants had to be created to make the power-driven machines. The power-driven machines, in net result, created more jobs than they displaced. In face, theoretically, more men were employed to make the same product. Therefore, the displaced person found himself doing the same job with better tools, be-

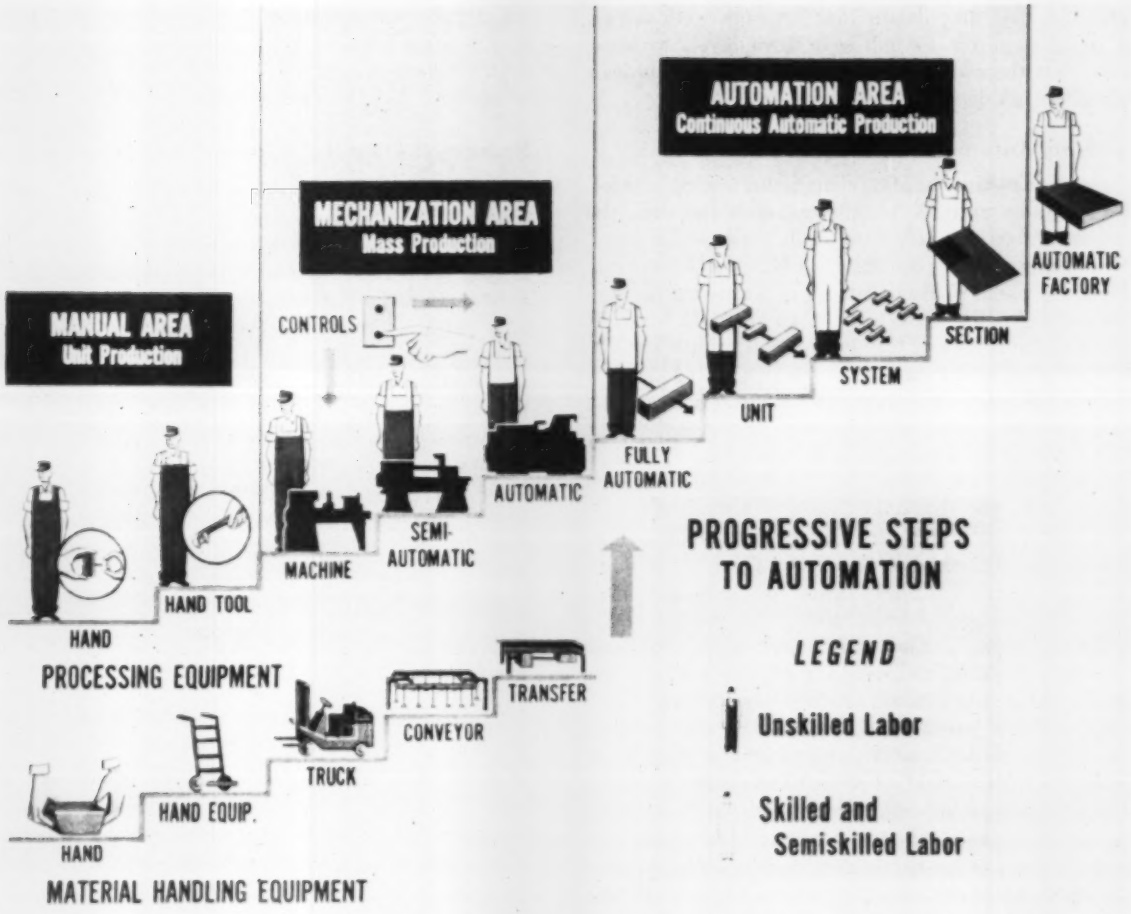

FIG. 1. Illustrated Stairway Portraying Progressive Movement of Manufacturing Methods to Automation. (Courtesy of General Electric, Manufacturing Services, Manufacturing Laboratory, Schenectady, New York.)

cause these tools were made available for him to use, and since the tools made it possible to employ more men doing the same work.

In the automated area machines are more automatic and more integrated with work-piece movement devices to perform a series of continuous operations. The degree of lessened physical effort on the part of the worker is greater than in the mechanized area. Practically all the physical effort has been transferred into the machine. The production worker in the automated area of manufacturing has been again upgraded—this time not as a skilled machine operator, but more in the area of a technician and a maintenance expert. Man becomes a machine attender. In the mechanized area man serves as a machine operator. Man uses more mental skills and less physical effort in the automated area.

An Unmistakable Meaning

Before one dares to expound upon the effect of automation on social and economic life of our accelerated increasing population (statistically speaking), one must first clearly visualize the demands placed on industry to produce goods and services which will cope with the expanding needs of our world population. With this basic understanding, one is better equipped to evaluate the meaning of automation and bring about a calmer and a saner appreciation of the mechanized development of industry and its impact on society.

Unquestionably automation will raise the standard of living for the working man, because, through automation, production volume can be attained to meet the demands. Thus the economic life for the average worker will have been improved through the abundance of goods and services at a price he can afford to pay. When purchasing power has been increased, everybody benefits.

Man's social life will change for the better through the automation method of manufacturing. Automation will change man's work and play habits. Today the average man devotes five eight-hour work days a week to his employer. He has two days a week for himself. Through

automation, man may devote four five-hour work days a week to his employer. He will have three days a week for himself, plus the additional leisure hours created through the shorter work day.

Classifying Automation

Through newspaper headlines, magazine leading articles, editorials, radio and TV commercials and speeches, the American Public is confronted daily with automation. This intensive publicity has accomplished just the opposite of what one would suspect. Instead of increasing the layman's understanding of the term, it has created a fear that mass unemployment and the degradation of man's incentive is just around the corner.

"Black pessimists have pictured automation as a Fifth Horseman of the Apocalypse, leaving mass unemployment and degradation of the human spirit in its wake." (3)

The other extreme claims that "Automation has been heralded . . . as the threshold to a new Utopia in which robots and 'giant brains' do all the work while human drones recline in pneumatic bliss." (3)

In 1952 a Harvard Business School graduate, at the age of about 21, produced a book called "The Advent of the Automatic Factory". This provocative study captured the eye of publishers, and within four years the book has been translated into French, German, Spanish and Japanese. This fact is presented to illustrate how the renaming of an old idea can awaken the public. Just how much harm or good this book will do, only time can answer.

Actually automation will bring about a new concept of work responsibilities. All through history man has been paid for the use of his hands. Automation brings less use of the hands and more use of technical knowledge. Workers, instead of operating precision machines, will attend these machines, thereby making less use of their hands. The trend, as a result of automation innovations, is that the worker will pay to use his hands in a form of recreation during off duty hours. In other words, the worker, who used to be paid for using his hands during working hours, will now pay others for the privilege of using his hands during off duty hours.

Those who classify automation as being limited to only one industry, and where production is sustained in mass quantity, are in error. By no means is automation peculiar to any one industry. Fundamentally, automation is an engineering technique that offers worthwhile results to all concerned, regardless of the area of application.

Applied automation requires the blending and coordination of know-how from several individuals and manufacturing plant departments. Executives in Sales, Marketing, Finance, Engineering, Personnel and Manufacturing are the key individuals involved in planning for automation. These coordinated actions will resolve into lasting economic benefits for people in all walks of life. The opportunities are unlimited. As of 1956, the surface has not even been scratched. Automation will find its way into many homes, commercial establishments, offices and industries which today are unknowns. It is now necessary to properly classify automation. Some standard way should be developed so that the public will attain a better understanding of the term and its meaning.

Broadened Planning

Automation planning involves the heart of the basic functions of producing goods and services. Instinctively, this heart is the production operation and processing. It is this basic function which must be visualized in the automatic factory. Design, material handling, storage maintenance and measurement are essential. Each of these is a never-ending factor in production. For example, the measurement factor determines quantity, quality, performance, identity and change, over and over again, throughout the production cycle from a raw material to consumer receipt. The function of each of the other factors is equally present in its respective area of the manufacturing operation or process.

Concept of Product Design

Prior to the advent of automation, the design engineer concentrated on the functional aspects of his design. He left the fabrication details wholly to the manufacturing personnel.

The concept of automation has forcibly focused the attention of the product designer on a more inclusive evaluation of his design functions. He is no longer responsible only for the functional aspect of his equipment, but now has an added responsibility. In addition to visualizing how the equipment will perform, he must further visualize how it is to be produced. The importance and influence of product design to automation is illustrated in Fig. 2. A careful analysis of this concept readily portrays the necessary insight required by design engineers of tomorrow and its effect in designing a product for automated manufacturing.

The nature of the product, the materials from which it is made, and the interchangeability of the product's component parts, plus the quantity demand, will govern the designer and the manufacturing method for which he will prepare his design. Fig. 3 illustrates the effect of these factors in the design of an ordinary chair. Note the change

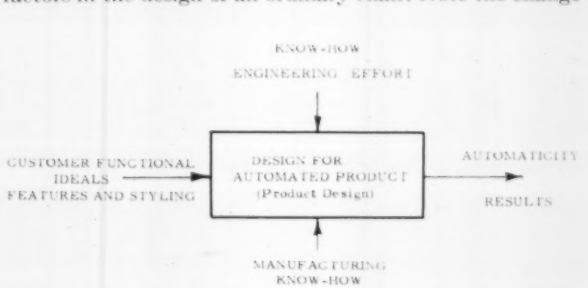

FIG. 2. Illustrated Diagram Portraying the Basic Factors Which Must be Considered in Designing a Product for Automation Application.

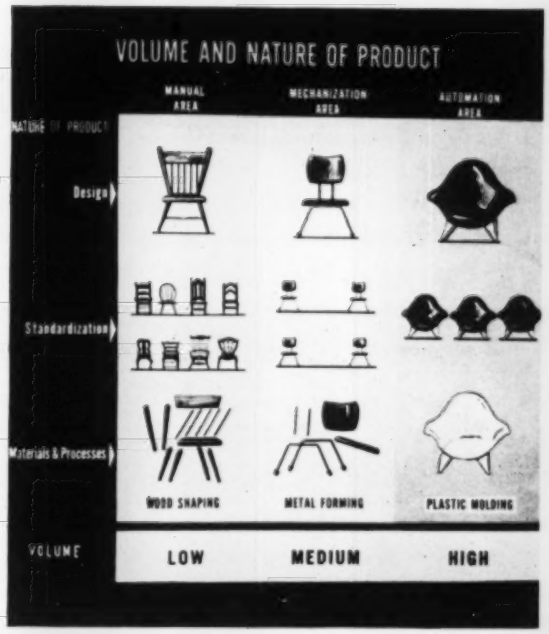

FIG. 3. Comparison of Volume and Nature of Product with Volume and Method of Manufacturing. (Courtesy of General Electric Company, from film, "This Is Automation".)

in appearance of the chair, and the ease of manufacturing, as the design moves from the manual area to the automation area of manufacturing.

The designer must consider the various levels of manufacturing operations. For example, in a product designed to be produced by manual methods, allowances must be made for inspection, assembling, testing and packaging. These allowances will vary greatly if the product is to be made by mechanical methods. Of course, a new and different concept must be placed on each of these items if the product is to be made by automated methods. Fig. 4 delves into this area in which some labor leaders and many economists fail to comprehend the significance and importance of raising the standard of living and the upgrading of workers. The less the manual inspection, the less the manual assembly, the less the manual testing, and the less the manual packaging, the more time man has to use his mental skills and the less tired (physically) man becomes during duty hours.

Following through with the philosophy portrayed in Fig. 4, we see the effect costwise in Fig. 5. This chart demonstrates the effect per unit of distribution cost in various manufacturing areas as it applies to materials, direct manufacturing labor, indirect labor, engineering and administration. Compare the values of each at the different manufacturing levels. Note the significant changes from hand production methods to automated manufacturing. Also, observe the influence and importance of each on the other, particularly direct labor, indirect labor and material utilization.

The intent of these illustrations is to focus the reader's attention on the factors which must be carefully weighed in devising a tool for measuring the extent of automation. It is just a matter of time, and it will be in the not-too-distant future, when such a tool will be developed which will lend itself to universal adaptation in determining the extent of automation projection.

Expanding Economy

Our rising generation of "leisure and abundance", a direct result of our current accelerated development in technology, has accepted this concept of leisure and abundance as *the* way of life and living. This concept, therefore, becomes the dominating factor behind the enormous consumer capacity. Consequently, the rising generation is emerging into a new era of social society, a new philosophy of living. This factor is producing a major shift in our economic and social concept of modern living, with many favorable consequences.

This economy of leisure and abundance is rapidly expanding our population. America's current rate of population change is approximately 6 newborns per minute. These six additional consumers of the leisure and abundance philosophy of life must be fed, clothed, sheltered and entertained. They play a very important role in the factors which go into the things which decide the extent of automation expansion. This six per minute rate of production of new consumers, projected into terms of population trends on an annual basis, means that in 1956 there will be more than 3,000,000 added to our rising generation, whose basic living philosophy is leisure coupled with abundance in goods and services. This is a conservative figure. In 1954 America's population jumped by more than 2,920,000.

This rate projected into the future indicates that the increase in America's population over the next two decades might be as much as 75 million, which would bring our population from the current 166 million to nearly 241 million.

Productivity-wise, this means a need for an accelerated surge in our production capabilities. Assuming that our

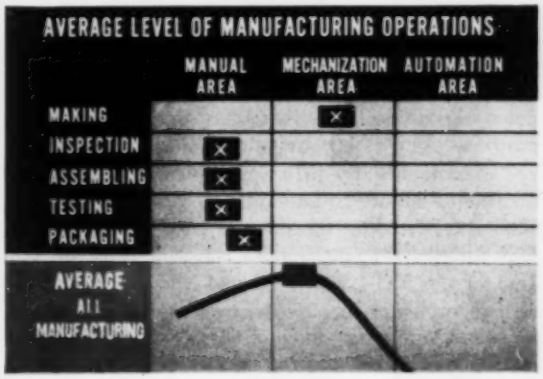

FIG. 4. Average Level of Manufacturing Operations. (Courtesy of General Electric Company, from film, "This Is Automation".)

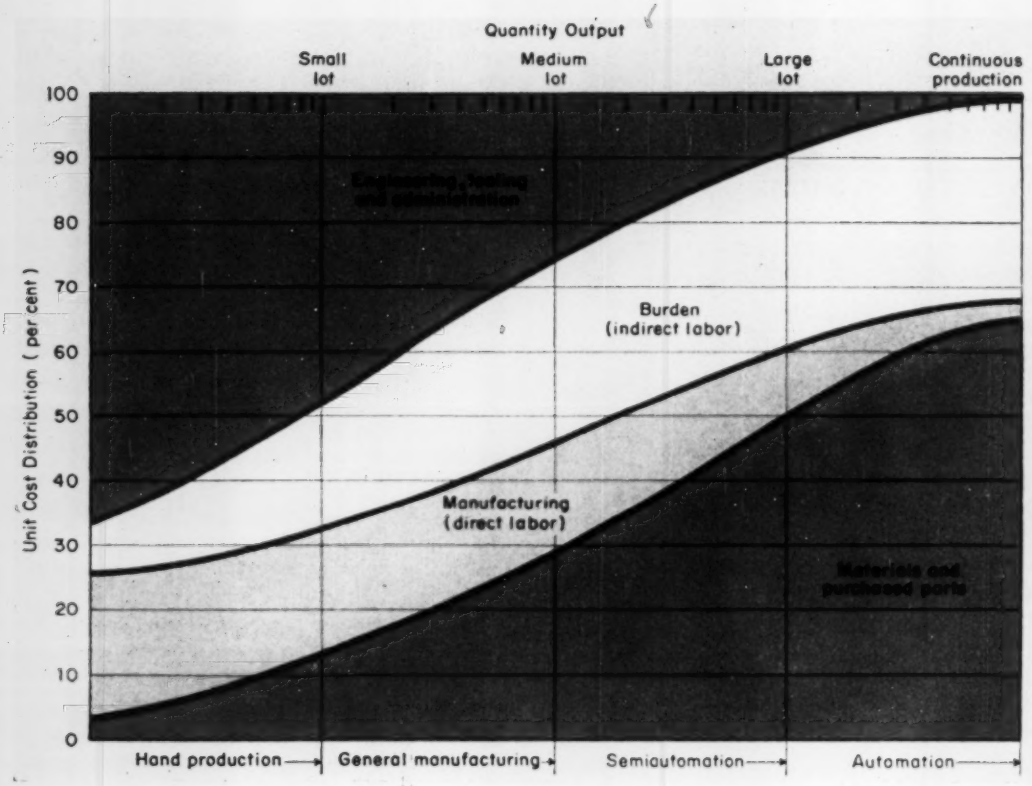

FIG. 5. Illustrates Unit Cost Ratio and Distribution Factors Charted in Relation to Production Output to Show the Changing Emphasis as Production Moves Into the Area of Automation. (Courtesy of R. W. Bolz, Penton Publishing Company, Cleveland, Ohio, *Automation*, p. 35, Nov. 1955.)

manufacturing processes will remain status quo, the productivity demand in America by 1976 would require a laboring force of about 112,000,000 to produce and distribute the needed goods and services. Analysis of population growth in various age groups reveals that the expected available laboring force by 1976 should be around 92 million. Our current labor market, as of April 1956, is 65 million; 13 million of these are employed directly in the production of goods. Currently there is a shortage of production workers to meet and cope with present production needs.

Today's 61 million automobiles employ 700,000 mechanics who do nothing other than service these cars for the owners. This is an equivalent of 1 service mechanic per 87 automobiles. By 1976 it is estimated that this rising generation of leisure and abundance will be operating 110 million cars. Holding the present ratio of 1 service mechanic for each 87 automobiles constant calls for a mechanic force of 1,264,368 in the field who will be employed full-time servicing cars for the owners. This means that from somewhere a new force of 564,368 workers will have to be found. Similar startling figures may be produced in TV, radio, telephone, aircraft, transportation, wholesale and retail service fields.

Need for an Ingenious Interpretation of Automation

A critical approach to the interpretation of the influence of automation on manufacturing methods is a must. With this thought in mind, Fig. 6 is presented. Here, an attempt is made to scientifically define automation. The figure illustrates the extent of the working functions of automation. This figure also focuses attention on one other factor. That is, to adopt automation methods of manufacturing demands the teamwork of many individuals spread over several manufacturing sectors. The figure also brings out into the open another problem. This is, who should be charged with the responsibility of directing and coordinating this team of carefully screened executives? Should it be an engineer, scientist, economist or managing executive, or should it be a combination?

Many people, in all walks of life, have expressed written and spoken opinions on automation. Each in his own professional endeavors falls into the category of *Expert* in his respective field, assuming of course, that each fully meets the requirements of his respective professional field. Just who is best qualified professionally to fill this need or gap created by the current inroads of automation? Would it not be logical to place this responsibility on a person who

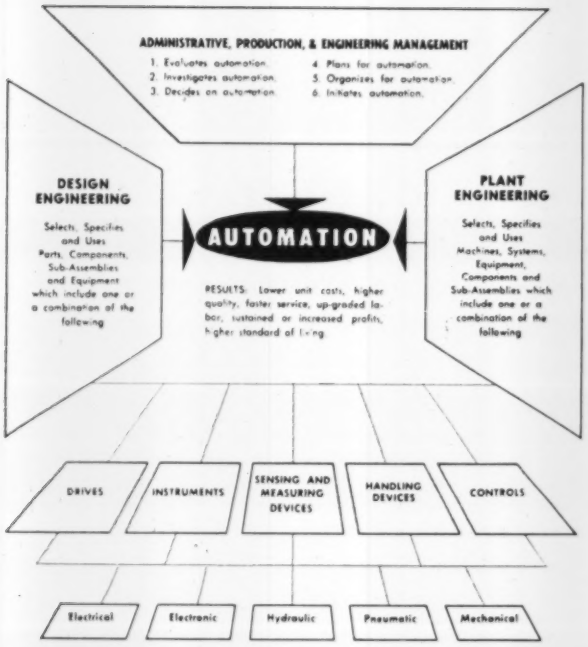
ADMINISTRATIVE, PRODUCTION, & ENGINEERING MANAGEMENT
1. Evaluates automation.
2. Investigates automation.
3. Decides on automation.
4. Plans for automation.
5. Organizes for automation.
6. Initiates automation.
DESIGN ENGINEERING
Selects, Specifies and Uses Parts, Components, Sub-Assemblies and Equipment which include one or a combination of the following
AUTOMATION
RESULTS: Lower unit costs, higher quality, faster service, up-graded labor, sustained or increased profits, higher standard of living.
PLANT ENGINEERING
Selects, Specifies and Uses Machines, Systems, Equipment, Components and Sub-Assemblies which include one or a combination of the following
DRIVES
INSTRUMENTS
SENSING AND MEASURING DEVICES
HANDLING DEVICES
CONTROLS
Electrical
Electronic
Hydraulic
Pneumatic
Mechanical

FIG. 6. Influences in The Adoption of Automation. (Courtesy R. W. Bolz, Penton Publishing Company, Cleveland, Ohio, *Automation*, p. 118, Nov. 1954.)

has a professional working knowledge of design, improvement, installation and integration techniques as they pertain to men, materials, machinery and the proper movement of each in the various levels of manufacturing processes? Would it be proper to assign such duties to a versatile industrial engineer with considerable experience in managing a manufacturing plant? Time answers many questions, and perhaps it will be the Time factor which will bring about this answer? What is your opinion? The author invites the reader to express his viewpoint on Automation and its significance to the world of tomorrow.

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Journal of Industrial Engineering

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Statistical Procedures in Stop Watch Work Measurement*

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It must be made explicitly clear at the outset that the subject of this discussion is work *measurement*—not standard setting, not methods improvement. Measurement means this daily business of using a stop watch to get a number that reflects what *is going on*—what the productivity of an operator on an operation currently is. Measurement, as such, varies in importance to different industrial engineers. Nonetheless, when it does occur, there are certain basic measurement questions that arise:

1. How many readings are required?
2. Are the data consistent?
3. What is the reliability of the final answer?

These questions are customarily handled by "hunch" and opinion, often debated vigorously, all of which is an unnecessary waste of engineering effort. For there are certain basic statistical techniques available to answer these questions correctly and unequivocally. This paper sets forth simple practical procedures, based on statistical theory, that every industrial engineer can use to answer these questions. The procedures require no more work than the customary "hunch" devices yet give a thoroughly objective approach to work *measurement*.

The measurement phase may appear trivial to many industrial engineers establishing incentive standards. That might well be true; there is certainly no attempt to indicate that our life problems in this profession are hereby solved. It is merely proposed to nail most of this measurement business down—inconsequential as some may think it to be—and permit valuable engineering intuition, creativity, and genius to get on with the other vexing daily problems that do require artistry since there is no science.

The Role of Measurement

To clarify some of the above, we might consider that two industrial engineering audiences are involved:

1. Those who have no incentive plan and are concerned with productivity estimates for costing, scheduling, and the like.
2. Those engaged in setting incentive standards.

The first group obviously has a high stake in good measurement. It isn't a trivial matter and this discussion should be appropriate.

For the second group, let us look at the three traditional steps in arriving at a standard:

1. Engineering the job
2. Measurement
3. Standard setting

The first of these—engineering the job—entails the establishment of methods, training the operator, and the like. The third—standard setting—is the process of specification, setting forth what productivity is desired for the money to be paid out. In this step, rating or levelling is employed, either directly or indirectly, as an aid to reasonable specification—the "fair day's work."

The second of these three steps—measurement—sandwiched in between the other two, as noted before, has varying importance depending on the particular views of the industrial engineer and the prevailing standards program. Some maintain that, in the one of several available pre-determined time systems they are using, measurement has already been done (as, indeed, has standard setting) and is therefore unimportant. Others feel that the on-the-spot measurement process is not a rigorous one, data being important only as a collection from which one *selects* a particularly appealing time value, again combining the last two steps. A third group generally attempts to carry out an on-the-spot measuring process to portray what *is going on* with respect to productivity. Using this as a base, they then determine a standard, employing judgment as to the "value" of the productivity observed. Measurement, here, is naturally more important, but how much more so is hard to say.

This discussion, concentrating on the measurement step, will appeal more to the last group. However, there is really no rejection intended of pre-determined time systems or the art of selecting a time value; those subjects are just beyond the scope of this discussion. The assumption throughout is that measurement is necessary in determining an incentive standard, or in its own right where there are no incentive standards; and, accordingly, there are certain basic measurement problems that must be handled. It is assumed, moreover, that engineering the job has been

* The writer is indebted to Dr. William G. Howe of the Scientific and Industrial Computing Laboratory, Kodak Park Works, for his thoughtful review and suggestions pertaining to the Development Notes.

completed and that what one does with the measurement value—rate, level, use it directly—is just what one has done all the time. In short, again, the subject is measurement.

Basic Measurement Questions

To reiterate, in any measuring process these basic questions need to be answered:

1. How many observations are required?
2. Are the data consistent?
3. What is the precision of the final answer?

The traditional use of judgment regarding work measurement data has egged on the critics recently. In the past few years it has been the fashion to comment adversely on time study practices, in admittedly brilliant critiques, on these very points of data handling (among numerous other points) (1). One qualification, though, that all industrial engineers should take to heart, was a remark (unpublished) by one of these critics (unnamed) to the effect that time study people are really no worse than chemists—they just get caught. Moreover, the questions *are* hard ones, and we industrial engineers need feel no shame in not resolving them earlier. The debt we owe these critics is large. In casting a sometimes harsh light on our traditional procedures, they have nonetheless pointed out and inspired considerable thinking on positive approaches such as set forth in this paper.

These measurement questions were recognized as statistical by the critics, and techniques were offered to aid in answering them. As presented, however, in all their mathematical glory, they tended to frighten a thoroughly pragmatic profession disturbed enough by English, let alone Greek; but the gap has been slowly closed particularly in the area of work sampling. And it is extremely important that it continue to be closed, so that there can be more responsible work measurement from the profession as a whole. This will not only help the practicing engineer in day to day analyses, but also render his daily experience of measuring repetitive human behavior more useful to research.

As in work sampling, the simple, practical procedures based on correct statistical theory enable one to *engineer the measurement* as we have traditionally engineered the job. The thoroughly practical end point is one of *controlling* at least part of the engineer's analysis and, hence, time.

A simple example will be described to show these procedures in action. The most elementary situation is pictured—a repetitive operation with one unit of measure and two auxiliaries. No doubt many questions will arise, but they will be deferred until the commentary, rather than slowing down the case history description. Full development notes, regarding the statistical content, are also presented.

A Simple Example

This was an operation with a main cycle (A) and two auxiliary elements (B and C). The occurrence frequency of Element B was random and was to be determined in the study. Element C had a fixed occurrence frequency—14 main cycles per 1 element C. The engineer used a basic five-step approach to this engineered time study.

Step 1—The Preliminary Estimate

He took 16 observations of one operator on the operation during a Tuesday morning. A random number table was used to randomize four groups of four observations each over the available $3\frac{1}{2}$ hour period. He extended the raw data from the continuous time studies taken over each group of four cycles. Data associated with methods not conforming to the right and left hand chart elemental description were eliminated. The results are shown in Table 1. The main cycle data were grouped in groups of four. A *range* (R)—the difference between the highest and lowest value—was obtained for each group. An average value ($\bar{X}$) was obtained for the main cycle and each auxiliary. He also determined average range ($\bar{R}$) for the main cycle.

With these values and the occurrence frequencies of B and C (B estimated at 8), he computed a preliminary estimate of the complete pro-rated cycle time, $\bar{\bar{X}}_T = 1.22$ minutes. The preliminary range value (R^*) was determined

TABLE 1

Results of Preliminary Study

(Time in minutes)

Main Element A			Element B	Element C
		Range of Groups of 4		
8:15	.90	.26	.57	2.16
	.88		.44	
	1.14			
	1.00		1.01	
9:30	.99	.47	*Random occurrence frequency*	*Fixed occurrence frequency*
	.90			
	.97			
	1.37			
9:45	1.09	.53	$f_B = \frac{16}{2} = 8$	$f_C = 14$
	.96			
	1.32			
	.79			
11:45	1.11	.33		
	.79			
	1.01			
	.78			
Total	16.00	1.59		

No. of observations = $N_A = 16$ $N_B = 2$ $N_C = 1$

Avg. Time = $\bar{\bar{X}}_A = \frac{16.00}{16} = 1.00$ $\bar{\bar{X}}_B = \frac{1.01}{2} = .51$ $\bar{\bar{X}}_C = 2.16$

Avg. Range = $\bar{R}_A = \frac{1.59}{4} = .40$

Preliminary Pro-rated Cycle Time = $\bar{\bar{X}}_T = 1.00 + \frac{.51}{8} + \frac{2.16}{14}$

$= 1.22$

Preliminary Range Value = $R^* = \bar{R}_A\,(1 + .12u)$

$= .4\,(1 + .12(2)) = .4\,(1.24) = .50$

by taking the main cycle average range which was $\bar{R}_A$ = .40, and multiplying it by (1 + .12u) where u = the number of auxiliary elements = 2. He used (1 + .12u) since he had a mixture of random and fixed auxiliary occurrence ratios. The values for other situations are set forth in the summary.

Determing $\bar{\bar{X}}_T$ and R^* completed Step 1.

Step 2—Design of the Study

a. *Probable Number of Observations to Make on the Main Cycle*

The engineer specified his desired precision E on the prorated cycle time as plus-or-minus 5%. That is, if the average time of this operator from constant study really was 1.22 minutes, he would be satisfied with a sampling answer from 1.17 to 1.27 minutes. Using E = 5%, $\bar{\bar{X}}_T$ = 1.22, and R^* = .50, he entered the Work Measurement Alignment Chart (Fig. 1) as demonstrated. He lined up E and $\bar{\bar{X}}_T$, noted the point of intersection on the S scale, lined up that point of intersection with R^*, and extended that line to the far right reading 62 as the number of readings to take on the main cycle (N_A).

b. *Plan of Observation*

He had already made 16 observations which left 62 − 16 = 46, at least, remaining. The procedure calls for groups of four so he selected the next highest multiple of 4, 48. The problem was then one of randomly scattering those 48, in 12 groups of 4, over the remaining two and one-half days—this was Thursday noon, he had a deadline of Friday morning. Each group of four required about 15 minutes of the engineer's time in all; there were 20 × 4 = 80 fifteen minute periods available; he selected 12 at random from the 80, using a random number table, thus setting up his observation plan.

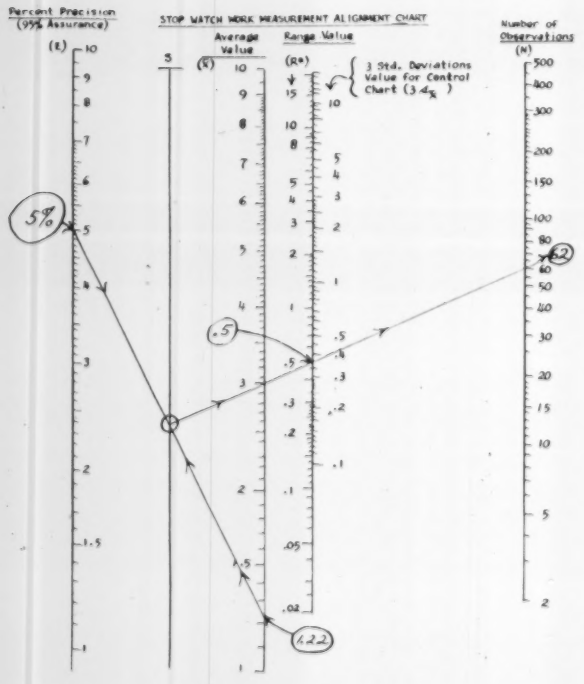

Fig. 1. Stop Watch Work Measurement Alignment Chart

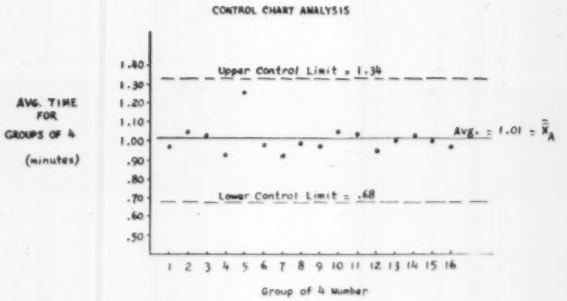
CONTROL CHART ANALYSIS
AVG. TIME FOR GROUPS OF 4 (minutes)
Upper Control Limit = 1.34
Avg. = 1.01 = X̄A
Lower Control Limit = .68
Group of 4 Number

Fig. 2. Control Chart Analysis

Step 3—Observation According to Plan

At the specified times over the three days, the engineer went to the area, observed four main cycles, and the associated auxiliaries, with continuous stop-watch studies, and recapped all the raw data (including the preliminary data) as shown in Table 2. Data belonging to non-specified procedures were not included. As in the preliminary study, data were grouped in groups of four in the main cycle, an average value ($\bar{X}_A$) for each group of four obtained along with a range value (R_A). An average ($\bar{X}$) was computed for each element and for the main cycle he computed an average range ($\bar{R}_A$). He determined the occurrence frequency for element B, then computed the final prorated cycle time ($\bar{\bar{X}}_T$ = 1.20) and a final range value (R^* = .56) using the same value (1 + .12u) set forth in Step 1.

Step 4—Control Chart Analysis of the Data

This final average of 1.20 minutes could only be considered as typical if the data making up that average were *consistent*. The engineer tested consistency by a control chart analysis of the data from the main element A as shown in Figure 2. He first plotted in sequence the $\bar{X}_A$ values (averages of groups of 4) and drew in the average line (1.01 minutes). Control limits were determined from the Alignment Chart (Figure 1) an extract of which is shown in Figure 3 for demonstration. Using the $\bar{R}_A$ value of .45, he entered the range value scale—the left hand side of the second scale in from the right. From the other side of that scale—the right hand side—he read off the 3 standard deviations value (3 $s_{\bar{X}}$) as .33. This value added to and subtracted from 1.01 gave him the limits of 1.34 and .68 respectively.

TABLE 2

Results of Complete Study

Random Time	Time Value	From Groups of 4		Random Time	Time Value	From Groups of 4		Random Time	Time Value	From Groups of 4	
		Avg ($\bar{X}_A$)	Range (R_A)			Avg ($\bar{X}_A$)	Range (R_A)			Avg ($\bar{X}_A$)	Range (R_A)
Main Element A											
	X_A				X_A				X_A		
8:15	.90	.98	.26	2:30	.82	.91	.29	2:30	.90	.93	.52
	.88				1.10				.68		
	1.14				.93				1.20		
	1.00				.81				.93		
9:30	.99	1.06	.47	3:30	.64	.99	1.16	8:45	1.26	1.00	.41
	.90				.66				.80		
	.97				1.80				.92		
	1.37				.84				1.07		
9:45	1.09	1.04	.53	8:00	.64	.97	.50	9:30	1.27	1.02	.46
	.96				1.01				1.12		
	1.32				1.14				.84		
	.79				1.09				.81		
11:15	1.11	.92	.33	10:45	1.02	1.05	.38	11:00	1.17	1.00	.33
	.79				.81				.84		
	1.01				1.18				.97		
	.78				1.19				1.03		
1:30	1.19	1.30	.26	1:15	1.11	1.04	.44	3:45	.97	.97	.28
	1.36				.76				.99		
	1.22				1.20				1.10		
	1.45				1.10				.82		
									64.59		7.14
2:00	.79	.97	.51	No. of observations = $N_A = 64$			Avg. time = $\bar{\bar{X}}_A = \frac{64.59}{64} = 1.01$				
	.97										
	.82						Avg. range = $\bar{R}_A = \frac{7.14}{16} = .45$				
	1.30										

Auxiliary Element B

Time value (X_B)
.57
.44
.60
.52
.33
.47
.40
.34
3.67

No. of observations = $N_B = 8$

Average time = $\bar{\bar{X}}_B = \frac{3.67}{8} = .46$

Occurrence frequency = $F_B = \frac{64}{8} = 8$

Auxiliary Element C

Time value (X_C)
2.16
1.86
1.83
1.90
1.80
9.55

No. of observations = $N_C = 5$

Average time = $\bar{\bar{X}}_C = \frac{9.55}{5} = 1.91$

Occurrence frequency = $F_C = 14$ (fixed)

Final pro-rated cycle time = $\bar{\bar{X}}_T = 1.01 + \frac{.46}{8} + \frac{1.91}{14} = 1.20$

Final range value = $R^* = \bar{R}_A (1 + .12\,u) = .45\ (1.24) = .56$

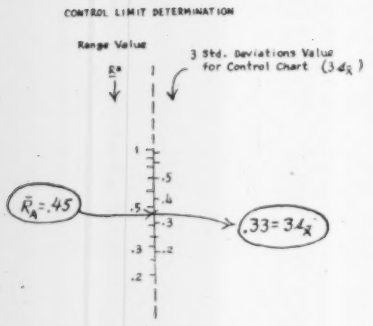

FIG. 3. Control Limit Determination

Since no points violated the limits, the data were in statistical control. There was consistency—there were no distinctly different causes in operation. There was a single chance cause system operating. Accordingly, the *overall* average value of 1.2 minutes could be accepted as typical and its precision determined in Step 5.

Step 5—Precision Check

With the data in statistical control—and only then—the engineer entered the Stopwatch Work Measurement Alignment Chart of Figure 1 with $\bar{\bar{X}}_T = 1.2$, $R^* = .56$, and $N_A = 64$ to determine E, the per cent precision. He lined up N_A on the far right with R^* and extended the line to the S scale and noted the point of intersection. He lined up that point of intersection with $\bar{\bar{X}}_T$ on the average value scale and extended the line to the far left scale reading off 5.6% as E. That meant he had defined $\bar{\bar{X}}_T$ as 1.2 minutes plus-or-minus 5.6% of 1.2 or 1.2 ± .07. More specifically, it meant that the interval of 1.13 minutes to 1.27 minutes had a 95% probability of containing the "true" average time—that time that would have been obtained from continuous study on the operator over the entire three-day period. This was felt to be sufficiently close to initial specification of ±5% and the measurement phase of his study was completed.

Commentary

Concluding the Example

Before commenting on various pertinent points, a conclusion to the case history is in order. The operator was rated in conventional form and a standard (specification) established by applying the average rating to the measured value. Here is the answer to one inevitable question regarding this approach, "What about rating?" The data, as listed, were raw data which might cause some to disagree; however, if it is not the engineer's custom to use an average rating, he can use rated data and subject that to this five-step plan.

In any event, these easy-to-use, practical steps, as in the example, enable the engineer, who is interested in *measurement*, correctly to answer the three basic measurement questions:

How many readings are necessary?
Are the data consistent?
What is the precision of the final answer?

Minor as these questions may appear to be in establishing incentive standards, the five-step procedure does permit the engineer to handle them routinely and move on to more difficult issues. Standard setting and all the human relations aspects of his job really require his intuitive "genius." Intuition applied to the basic measurement questions is inappropriate and wasteful, since, to compete with statistical theory, it amounts to the engineer doing summations, long division, and square roots in his head—difficult at best.

The Complete Five-Step Procedure

This example did not have all possibilities even for the simple type example described. The complete procedure is outlined in Table 3 indicating several of the alternative conditions with regard to auxiliaries and the associated computations.

Groups of Four Simplify Estimating Variation

Turning now to some specific aspects of the procedures, the question "Why groups of four?" always arises. Groups of four simplify estimating variation. In order to answer the basic measurement questions, some estimate of the variation of the data is necessary. Range is an easy way to get this estimate, much easier than calculating standard deviation the long way. Range from groups of four standardizes the procedure, adding to its simplicity at little sacrifice to the accurate determination of the number of readings necessary, control limits, and final precision.

To many engineers, admitting to variation, let alone estimating it, seems to smack of defeatism and generally sloppy engineering. This is a difficult notion to dislodge but here is a brief thought in that connection: Variation in the measurement of *any* phenomenon is such a fact of life that even nuclear physicists (the most sacro-sanct of all scientists) predicate their spectacular results on probability theory. They indeed admit their knowledge is just "good enough"—that the idea of variation, "chance" or unexplained variation at that, springs from their frustration. There isn't the time, money, or intelligence to find out the causes at this time. Is human behavior better known?

Groups of Four and Control Charting

As indicated in the example, the control chart tested *consistency*. Note that no comment was made about the distribution of individual main cycle time values. There really was little concern about that distribution other than its *consistency* over the time span of measurement. Such

TABLE 3

5 Steps of Statistical Stop Watch Work Measurement

Step 1 *Preliminary Estimate*

a. Previous information—or—16 random observations (groups of 4)

b. Compute the average value ($\bar{\bar{X}}$) and the average range ($\bar{R}$) for the main cycle. For each auxiliary element compute $\bar{\bar{X}}$.

c. State occurrence frequencies of auxiliaries ($\bar{f}_B, \bar{f}_C$, etc.)—note whether known or estimated from the study

d. Compute the pro-rated cycle time estimate:

$$\text{pro-rated cycle time} = \text{main cycle time} + \frac{\text{aux. } B}{\text{occurrence}} \text{ etc.}$$

$$\bar{\bar{X}}_T = \bar{\bar{X}}_A + \frac{\bar{\bar{X}}_B}{\bar{f}_B} + \text{- - - - -}$$

Step 2 *Design the Study*

a. *Determine the number of readings to make on the main cycle* (N_A)

(1) Specify E, the desired precision on $\bar{\bar{X}}_T$

(2) Determine the range value (R^*):

for any one element: $R^* = \bar{R}$

for overall pro-rated cycle — auxiliary frequencies:

- known: $R^* = \bar{R}_A\ (1 + .1u)$
- estimated: $R^* = \bar{R}_A\ (1 + .15u)$
- a mixture: $R^* = \bar{R}_A\ (1 + .12u)$

where $\bar{R}_A$ = main cycle $\bar{R}$; u = number of auxiliaries

(3) Using E, R^*, and $\bar{\bar{X}}_T$ (from Step 1) determine N_A from nomograph

b. *Plan of observation*—Use a random number table and randomly distribute groups of 4 over the available time period

Step 3 *Observation According to Plan*

a. Recap the data for the main cycle and each auxiliary in groups of 4:

for main cycle:
- $\bar{\bar{X}}_A$ groups of 4 averages
- R groups of 4 range
- $\bar{R}$ average range

for main cycle and each auxiliary: $\bar{\bar{X}}$ final average

b. State occurrence frequencies of auxiliaries—note if known or estimated

c. Compute pro-rated cycle time $\bar{\bar{X}}_T = \bar{\bar{X}}_A + \frac{\bar{\bar{X}}_B}{\bar{f}_B} + \text{- - - - - - - -}$

Step 4 *Control Chart Analysis*

a. Chronological plot of $\bar{\bar{X}}_A$ values (main cycle averages of groups of 4)

b. Determine 3 standard deviation limits ($3S_{\bar{X}}$) using $\bar{\bar{X}}_A$ and a range value (R^*) = $\bar{R}_A$ (average range, main cycle) in the nomograph

c. In or out of control limits? The points must be in to insure *consistency* and, therefore, that $\bar{\bar{X}}_T$ is a usable average value.

Step 5 *Precision Check*

Use the nomograph with N_A, $\bar{\bar{X}}_T$ (Step 3) and the final R^* (see Step 2 for the rules) and determine E_T, the percent precision on $\bar{\bar{X}}_T$.

a simple consistency test as the control chart would not have been possible, however, without averages from groups of four. There are many possible frequency distributions of individual time values requiring equally as many possible tests of consistency if individual data were to be tested. Averages of groups of four conveniently form, in most cases, only *one* type of distribution *regardless* of the distribution of individual values—a normal frequency distribution. Therefore, one consistency test can be employed on these averages, the control chart. This is considered in more detail in the development notes.

The Fundamental Importance of Consistency and Control Charting

That the groups of four make a consistency test practical is perhaps less startling to the uninitiated than the fact of such a test at all. This control chart test is really the heart of the matter; it points up the *acceptance of variation* and that *consistent* does not mean *identical*. Just looking at the data of Table 2 undoubtedly raises questions as to why such variation existed. Thoughts of different methods come to mind first or changes in pace due to changes in "effort." These did take place along with a product mixture and probably many others as well. Lots of observable things went on that apparently contributed to variation but from a *measurement* point of view, they were all part of the current system. The engineer's main interest was whether or not that system was homogeneous; the variation might give him clues as to what to specify (rating)—as to what might be expected. But the method was established and spelled out in elemental form (right and left hand chart); the operator was trained; methods variations were unconscious and small, and below the engineer's chosen level of description; the engineer eliminated any data which came from non-specified procedures (major methods differences, talking, fumbles, and so forth) for separate treatment; and the resulting data showed statistical control. Whatever causes did prevail, they were "chance" causes, blending randomly and producing a homogeneous time result. The cycle time consistency for this operator coupled with the methods description at the level of refinement chosen by the engineer, gave an *operational definition* to the operation—measured what *was going on*.

Out-of-Control Situations

An out-of-control point requires *investigation*. It means there's a rat in the woodpile—something different occurred. That "something" must be identified, *all* data associated with it eliminated, and the control chart recomputed. Recall that data belonging to non-specified procedures are eliminated upon *observation* by the engineer. So, the assignable cause detected by the control chart usually is a situation demanding a separate allowance, a separate standard or some more units of measure. If it really appears to be part of the system as the engineer chooses to describe the system, then the underlying distribution is probably too skewed (lopsided) to be normalized by groups of four. Larger groupings (such as eight) should then be made and appropriate limits set on those averages to test consistency. (See Development Notes).

Another out-of-control situation arises when the variation from random time period to random time period (between groups of four) exceeds the variation within a time period (within groups of four). If this is important to the engineer and is a condition he wants to correct (therefore not specified), then it must be investigated. If it is more or less expected, then a different consistency test is in order. Taking averages of groups of four themselves in groups of four, determining the range and average range, multiplying that by 2 for an R^* value, and using the nomograph, will give appropriate limits. Consistency, in such a case, is called "grand stability" by Abruzzi (1).

The Control Chart Simplifies the Engineer's Measurement Job

From this discussion it would appear that anything goes—that with sufficient manipulation one can call just about any data consistent. And this is true, since by and large, in work *measurement* things are pretty consistent and statistical control does prevail. *The control chart serves more in a preventive role than in a detecting role*, keeping the industrial engineer from his major work measurement vice—over-identification. This practice leads to casual data selection and eliminating by "hunch" under the guise of measurement. But it's understandable. The observer is at the same level as the phenomenon observed and has the natural inclination, borrowed from the physical sciences (where the level is much higher) to label every minute event, thereby mistaking refinement for insight. The use to which such minutiae can be put is still debatable lacking, as it does, the apparently necessary psychological factors that affect motivation. The control chart usually tells the industrial engineer that he hasn't a worry in the world when his borrowed intuition says the system is shot with problems, *and the control chart is right*. If the engineer wants to measure what *is going on*, statistics makes it simpler and quicker than he is probably accustomed to, yet thoroughly correct. Whether he *likes* what he sees is another question; if he *thinks* things will be different under another set of economic conditions, fine and dandy. That is not measurement, however, and the linkage between what is and what will be under changed conditions has yet to be unequivocally established.

Elemental Studies

On a less philosophical plane, consider the timing of the overall cycle in the example. Elements of that could have been used but they tend to have dependent variation. Usually, the precision on elements as observed is less than on the overall cycle with the same number of observations since the relative variation of elements is greater. The independent component of variation can be ferreted out by some complex techniques (see Abruzzi (1) and Rowe (3)). But, from a measurement point of view, the overall cycle is the item of interest and ought to be the item measured.

Randomization

The idea of randomization is not new in work measurement—it's the basis for work sampling. But it does pose some problems on stopwatch work measurement. Either short run jobs or deadline requirements tend to make it difficult in certain instances. Statistically, there's no loss; the number of readings, statistical control, and precision can still be determined—indeed, they need to be. But as the time span of measurement diminishes, there is less coverage of product variations, auxiliaries, and the like. In other words, *accuracy* suffers. Only by judgment or other measurements can the engineer estimate the effect of such reduced coverage.

Randomization of the time study sample permits greater coverage and resulting precision statements have greater practical meaning. It's to the engineer's practical advantage if he can randomly sample; but this five-step approach applies even if he cannot randomly sample.

Measuring More Than One Operator

This approach can be used with a collection of operators if it is desired. The process would call for a random selection of four operators for one cycle each in each group of four. This is definitely preferable to a group of four made up of just *one* operator's time since between-operator variability is always appreciable. Whether or not this approach is taken on a large job depends on the engineer's eventual use of the measured value. Since this is outside the discussion, it is sufficient to say that measuring a group of operators collectively, if the engineer wants to do it, can be done as described above.

Preliminary Estimate of Sixteen Readings

Sixteen readings is an empirical guide only. The nomograph will work for preliminary samples of 12, 8 or 4 but with a progressive tendency to underestimate the number of readings required. Since determining the number of readings is not necessarily a one-shot affair but can be done as more data are collected, it might not be a bad routine to look at the picture earlier—say after eight observations.

This is particularly true of operations with a low relative variation. However, sixteen has proved to be practical for the simpler practice of determining the number of readings just once, as called for in the five-step procedure.

Lack of a Range Chart

Even the most casual students of quality control will note the absence of a range control chart. Work measurement differs from quality control in that there's no concern about the individual item. A range chart is designed to tell whether or not individual pieces are being produced consistently—sort of a tactical consistency versus the longer range strategic consistency that the $\bar{X}$ chart tests. In work measurement the individual cycle time is of little interest in itself; attention is focused on central tendency ($\bar{X}$). This is all from a *measurement* point of view, of course; from a methods point of view, inconsistency in variation might be a clue to some better methods. An R chart, however, may not automatically be the right consistency test since the distribution may be skewed. More complex statistics would be involved. In work measurement then, a range control chart is unnecessary since we are not interested in the behavior of individual cycle times.

Summary

It is not easy to discuss any isolated phase of work measurement. There is so much interaction. The attempt here has been to say in effect to the industrial engineer, "If it's your practice to measure and if you believe you get something out of it, here are some simple statistically based techniques to help you." There has been no intention to advocate a fundamental role for on-the-spot measurement in incentive standards setting. Pre-determined time systems, selecting time values, rating, leveling, whether or not standards are even appropriate—none of these are within the scope of this paper. Some of the points raised predict probable arguments from engineers who really don't *believe* in measurement (who, indeed, *may* be a lot wiser) and discussion really can't take place since premises differ.

But for those who do measure, there is almost a professional responsibility on you to measure well and objectively. Besides giving your daily business more stature and respectability, besides improving your analytical prowess, and besides making your measurement work more effective economically, you will be serving research enormously. The laboratory for industrial human behavior is industry. Only as your measurement experiences are uniformly recorded and made available, can the innumerable hypotheses about human behavior be tested, reformed, retested—slowly evolving some quantitative notions on what makes us tick, at least in the industrial atmosphere. Work Measurement is one of the most extensive front lines of social measurement; it has a wonderful opportunity to contribute substantially to man's knowledge about himself.

In the meantime, the industrial engineer still has to eat. Quite frankly, with statistical techniques, he can tap the mother lode and keep in shoes for some time to come. There are more complex work measurement problems than the simple repetitive operation, to be sure. The complex statistics on those problems will be shaken down, though, and a more complete work measurement methodology developed. The simple procedures put forth here are an important background to such an eventual approach; familiarity with them through extensive use can lead to good payoffs now and in the future.

Development Notes

A. *Nomograph*

1. *Sample Size and Precision Determination*

The nomograph solves this expression:

$$E = \frac{97\bar{R}}{\sqrt{N}\,\bar{X}}$$

$\bar{R}$ = average of ranges for groups of size 4.
N = number of observations.
$\bar{X}$ = average value
E = confidence interval (approximately 95%) on $\bar{X}$ expressed as a per cent of $\bar{X}$ and called per cent precision.

It is based on the more general expression:

$$\frac{2s_{\bar{x}}}{\bar{X}} = \frac{2s}{\sqrt{N}\,\bar{X}}$$

and uses

$$\frac{\bar{R}}{d_2} = \frac{\bar{R}}{2.059} = s \qquad (n = 4)$$

2. *Control Limits for* $\bar{X}$

The second scale in from the right solves for this expression:

$$3s_{\bar{X}} = A_2\bar{R}$$

$3s_{\bar{X}}$ = 3 standard deviation value for averages of groups of 4.
$\bar{X}$ = average of a group of 4.
A_2 = .729

3. *Comments*

a. Note that with this procedure, in solving for N in the preliminary estimate, one cannot specify the probability of getting the desired confidence interval. This probability is approximately 50%—that is, there's a 50% chance that the sample size read from the nomograph will produce the specified precision or better. But sample size determination is not a one-shot affair; it can be redetermined progressively as data are collected and over or under estimates corrected.

A more conservative procedure that permits

specifying the probability of getting a desired confidence interval is set forth in:

Harris, M., Horvitz, D. G., and Mood, A. M., "On the Determination of Sample Sizes in Designing Experiments," *American Statistical Association Journal*, September, 1948.

b. Using $2s$ as a 95% approximation does not introduce any practical error. The t distribution values theoretically, should be used but, at worst, the error is $\frac{1}{2}$% or so in the precision statement using 2 throughout.

B. *Overall Procedure*

1. *Groups of 4*

The main point in looking at averages of groups of 4 is to test *consistency* (statistical control). The 3 sigma control chart is very convenient but requires that the plotted data ($\bar{X}$) be normally distributed. Averages of groups of 4 will form approximately normal distributions from parent distributions as skewed as a x^2 with 3 degrees of freedom.

The distribution of sums of samples of 4 (x^2, $3 \times 4 = 12$ d.f.) from such a distribution has a 1% point at 26.2. The mean (12) plus 3 sigma ($3\sqrt{24}$) is 26.7. Accordingly, taking action on a 3 sigma control limit basis in such a case is practically comparable to the case of complete normality. There is only a slight tendency to get out-of-control points from non-assignable causes.

This skewness limit covers most typical time study distributions. As noted before, we are interested in determining *consistency* regardless of the shape of the distribution. More highly skewed distributions will show up as out-of-control. They usually require another unit of measure but they can be tested for consistency using a larger n and the associated A_2 factor for limits on $\bar{X}$.

So the selection of $n = 4$ was empirical. A larger n would give less opportunity to look at variability; a smaller n would not normalize essentially typical time study distributions.

2. *The Behavior or Range in Non-Normal Populations*

This procedure admits to handling non-normal data but the use of range is customarily associated with a normality assumption. Errors are introduced but they are small and are of no practical importance. There is a slight bias towards underestimating s and setting closer limits. This has been verified in experimental work (unpublished report) done by Mr. R. H. Morris, Industrial Computing Laboratory, Kodak Park. A complete mathematical treatment is in the "Distribution of Range in Certain Non-Normal Populations", H. A. David, *Biometrika*, December, 1954 (see, particularly, page 467, paragraph 4.)

3. *Confidence Intervals in Non-Normal Populations*

The confidence interval form is usually associated with a normality assumption on the distribution of sample means. In computing N from a preliminary study of 16 or computing a final precision statement, this is easily met. Means from samples of size 16, for instance, will very closely approximate a normal distribution when the parent population is as highly skewed as x^2 with one degree of freedom. So, regardless of what the parent population is like, the Central Limit Theorem permits the normal distribution confidence interval statement with the sample sizes that are customarily encountered.

C. *Treatment of Auxiliaries*

1. The General Model

Consider the expression:

$$E_T = \frac{200 s_{\bar{X}_T}}{\bar{X}_T} \qquad E_T = \text{percent precision on the complete pro-rated cycle}$$

$$\bar{X} = \text{Complete pro-rated cycle} = \bar{X}_0 + \frac{\bar{X}_1}{\bar{f}_1} + \frac{\bar{X}_2}{\bar{f}_2} + \cdots + \frac{\bar{X}_u}{\bar{f}_u} = \sum_{i=0}^{u} \frac{\bar{X}_i}{\bar{f}_i}$$

i = element no. = 0, 1, 2, $\cdots u$

u = No. of auxiliaries

$i = 0$ refers to the main cycle

$$\bar{f}_i = \frac{N_0}{N_i} = \text{occurrence ratio of auxiliary element } i$$

N_0 = no. of observations of main cycle

N_i = no. of observations of auxiliary element i

$$s^2_{\bar{X}_T} = s^2_{\bar{X}_0} + \frac{s^2_{\bar{X}_1}}{\bar{f}_1} + \cdots + \frac{s^2_{\bar{X}_u}}{\bar{f}_u} = \sum_{i=0}^{u} \frac{s^2_{\bar{X}_i}}{\bar{f}_i}$$

$$\frac{s^2_{\bar{X}_i}}{\bar{f}_i} = \frac{\bar{f}_i^2 s^2_{X_i} + \bar{X}_i^2 s^2_{f_i}}{\bar{f}_i^4}$$

$$s^2_{\bar{X}_i} = \frac{s_i^2}{N_i} \quad \text{and using } s_i = \frac{\bar{R}_i}{d_2} \quad s^2_{\bar{X}_i} = \frac{\bar{R}_i^2}{d_2^2 N_i}$$

$$s^2_{\bar{f}_i} = \frac{s^2_{f_i}}{N_i} \quad \text{and using } s_{f_i} = \frac{\bar{R}_{f_i}}{d_2} \quad s^2_{\bar{f}_i} = \frac{\bar{R}^2_{f_i}}{d_2^2 N_i}$$

Substituting:

$$\frac{s^2_{\bar{X}_i}}{\bar{f}_i^2} = \frac{1}{d_2^2 N_0}\left(\frac{\bar{R}_i^2}{\bar{f}_i} + \frac{N_i^3 \bar{X}_i^2 \bar{R}^2_{f_i}}{N_0^3}\right) = \frac{1}{d_2^2 N_0}\left(\frac{\bar{R}_i^2}{\bar{f}_i} + Q_i\right)$$

and

$$s^2_{\bar{X}_T} = \sum_{i=0}^{u} \frac{s^2_{\bar{X}_i}}{\bar{f}_i} = \frac{1}{d_2^2 N_0} \sum_{i=0}^{u} \left(\frac{\bar{R}_i^2}{\bar{f}_i} + Q_i\right)$$

$$2 s_{\bar{X}_T} = \frac{.97 \sqrt{\sum_{i=0}^{u} \left(\frac{\bar{R}_i^2}{\bar{f}_i} + Q_i\right)}}{\sqrt{N_0}}$$

and

$$E_T = \frac{97\sqrt{\sum_{i=0}^{u}\left(\frac{\bar{R}_i^2}{\bar{f}_i} + Q_i\right)}}{\bar{X}_T\sqrt{N_0}}$$

This is the nomograph form with these arguments: E_T as the per cent precision of the overall pro-rated cycle, $\bar{X}_T$ as the average value, N_0 as the number of readings in the main cycle, $\sqrt{\sum_{i=0}^{u}\left(\frac{\bar{R}_i^2}{\bar{f}_i} + Q_i\right)}$ as the range value R^*

2. Simplifying

$$\sqrt{\sum_{i=0}^{u}\left(\frac{\bar{R}_i^2}{\bar{f}_i} + Q_i\right)}$$

Consider this as

$$\sqrt{\left(\sqrt{\sum_{i=0}^{u}\frac{\bar{R}_i^2}{\bar{f}_i}}\right)^2 + \left(\sqrt{\sum_{i=0}^{u}Q_i}\right)^2}$$

which is of the form

$$\sqrt{X_0^2 + X_1^2} = \sqrt{\sum_{i=0}^{1}X_i^2}$$

This has a lower bound X_L where X_L = larger X_i. The upper bound is $X_L\sqrt{2}$. The approximation of $\sqrt{\sum_{i=0}^{1}X_i^2}$ leans toward the lower bound and the following empirical relationship has proved successful:

$$qX_L = X_L\sqrt{2} - \frac{X_L\sqrt{2} - X_L}{\sqrt{2}}$$

$$qX_L = 1.1X_L$$

(for a middle point between bounds one would divide by 2 instead of $\sqrt{2}$)

X_L is almost always X_0 or $\sqrt{\sum_{i=0}^{u}\frac{\bar{R}_i^2}{\bar{f}_i}}$ since $\sqrt{\sum_{i=0}^{u}Q_i}$ varies inversely with N_0^2 and is usually very small.

$$\therefore \sqrt{\sum_{i=0}^{u}\left(\frac{\bar{R}_i^2}{\bar{f}_i} + Q_i\right)} \leqq 1.1\sqrt{\sum_{i=0}^{u}\frac{\bar{R}_i^2}{\bar{f}_i}}$$

Now, $\sqrt{\sum_{i=0}^{u}\left(\frac{\bar{R}_i^2}{\bar{f}_i}\right)}$ can also be simplified in a similar fashion. This is also of the form $\sqrt{\sum_{i=0}^{u}X_i^2}$ where $X_i = \frac{\bar{R}_i}{\sqrt{\bar{f}_i}}$. The empirical approximation here for $u = 1, 2, \cdots, 10$ is:

$$qX_L = X_L(1 + .1u)$$

X_L is invariably X_0 or $\frac{\bar{R}_0}{\sqrt{\bar{f}_0}} = \bar{R}_0$ since $\bar{f}_0 = 1$ and all other $\bar{f}_i$ are much larger (such as 8 or 14 or even 50).

So:

$$\sqrt{\sum_{i=0}^{u}\left(\frac{\bar{R}_i^2}{\bar{f}_i}\right)} \leqq \bar{R}_0(1 + .1u)$$

and

$$\sqrt{\sum_{i=0}^{u}\left(\frac{\bar{R}_i^2}{\bar{f}_i} + Q_i\right)} \leqq 1.1\bar{R}_0(1 + .1u) \leqq \bar{R}_0(1 + .15u)$$

If the auxiliary ratios ($\bar{f}_i$) are all known then all $Q_i = 0$ since $\bar{R}_{f_i} = 0$ and the approximation rule $R_0\ (1 + .1u)$ is used. If the auxiliary ratios are all determined from the study by sampling, then all $Q_i > 0$ and the approximation rule $\bar{R}_0\ (1 + .15u)$ is used. For any inbetween situation of partly known and partly sampled occurrence ratios, the rule $\bar{R}_0\ (1 + .12u)$ is suggested as a compromise.

3. The Complete Formula for Computation:

$$E_T = \frac{2\sqrt{\sum_{i=0}^{u}N_i\left(s_i^2 + \frac{N_i^2\bar{X}_i^2 s_{f_i}^2}{N_0^2}\right)}}{\sqrt{N_0^3}\bar{X}_T}$$

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Work Sampling Applied to Long Cycle Operations Performed by a Variable Labor Force

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If you have used Work Sampling in your plant or business, the chances are that most of your studies have been made on short cycle, highly repetitive operations performed by individual workers. In these studies you feel confident that Work Sampling will give unbiased and reliable percentage estimates of the elements you have recorded, and, further, the precision of these Work Sampling estimates can be calculated by means of statistical confidence intervals. However, these routine calculations do not apply for Work Sampling studies on long cycle operations performed by a variable labor force. Consider the problem of estimating the percentage distribution of worker activity for a long cycle operation where random samples are taken of one or more crews of workers of varying size working simultaneously on a single large assembly such as an airplane. An application such as this raises two important questions. First, will the estimates be accurate, i.e., will they be unbiased estimates of the true universe percentages? Second, what is the appropriate sample size to be used in assessing the precision of the estimates—the number of observations, the number of crews observed, the total number of workers observed, or some other value?

These are clearly problems which will require detailed mathematical analysis before generalized answers can be obtained. The purpose of this paper, which is based on a Monte Carlo study of an experimental universe is to highlight these problems which have not been treated in the literature to date, and to provide answers for the specific work situation studied here. The results of this investigation indicate that Work Sampling methods will give valid (unbiased) estimates of worker activity percentages for the specific operation studied which involved a variable labor force performing a long cycle operation. Further, in assessing the reliability of the Work Sampling estimates, the proper sample size was found to be the number of independent "crews" observed in the study. A "crew" is defined as one or more workers performing a task in which the activity of any crew member is dependent upon the activity of others in the same crew, while the crew activities are independent of each other.

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The Experimental Universe

The experimental universe used in this study was a condensed production all-day time study of an operation performed at the Lockheed Aircraft Corporation in Marietta, Georgia. The universe consisted of 24 consecutive shifts which comprised one complete cycle of this operation. The activities in this operation were classified into nine descriptive work classifications or elements (A through G, plus I and J) and one miscellaneous work classification (H).* The universe percentages of worker time spent in each category are given in Table I under the column headed p'.

The Sampling Experiment

In this investigation, 50 complete Work Sampling studies were made by taking 366 random sample observations per study from the experimental universe. Actually, these random samples were stratified by taking 16 random samples per 8-hour work shift, and proportionately smaller samples for the two fractional shifts in the experimental universe. An observation consisted of recording the activity of each worker assigned to the operation at the time of the observation.

For each of the 50 Work Sampling studies the per cent occurrence of each work classification was determined from the total number of workers observed who were engaged in the work classification in question, divided by the total number of workers observed in all ten work classifications. Collectively, these studies gave 50 estimates of the percentage occurrence for each work classification; these individual estimates are denoted by p. These 50 percentage estimates were then averaged to obtain a grand average, $\bar{p}$, for each of the ten work classifications. The frequency distribution of the percentage occurrence of work classification E for the 50 Work Sampling studies is shown in Figure 1.

As per normal Work Sampling procedure the variance

* Regulations will not permit a detailed description of these elements.

of the sampling error for a single study might be estimated for each work classification by means of the formula for the variance of the binomial distribution, as given in (1):*

$$\sigma_t^2 = \left[\frac{p(100 - p)}{n}\right] \tag{1}$$

where n = the number of observations made (i.e., 366). Since we are dealing with a known universe in this study, the sampling error variance can be expressed by (2):

$$\sigma_{t'}^2 = \left[\frac{p'(100 - p')}{n}\right]. \tag{2}$$

This formula, as defined, would be acceptable as long as only one operator was observed at each observation. However, when the number of operators exceeds one, some modification of the formula is necessary such as shown in (3):

$$\sigma_T^2 = \left[\frac{p'(100 - p')}{nK}\right] \tag{3}$$

where K = the average number of "effective" samples (operators) per observation.

A discussion of the physical interpretation of K is in order at this point. First, K can range from a minimum of one to a maximum equal to the average number of workers per observation. If the operation was such that the activities of the workers were perfectly correlated, i.e., workers are always engaged in a common activity, then K should equal one. If the operator activities have zero correlation, i.e., activities are statistically independent, the K should equal the average number of workers per observation. Between these limits lies a continuous range of values, however, one particular value is important in this study. If the workers are organized into crews with perfect correlation of activities within a crew and zero correlation of activities between crews, K should equal the average number of crews per observation.

The observed variability in the 50 study estimates for each work classification can be calculated by the root-mean-square deviation formula given in (4):

$$\sigma_0^2 = \sum_{i=1}^{N} \frac{(p_i - \bar{p})^2}{N - 1} \tag{4}$$

where N = 50, the number of Work Sampling studies made, and p_i = value of the percentage occurrence of the work classification in question for the i^{th} Work Sampling study. Since σ_T^2 and σ_0^2 are both estimates of the same error variance, they can be equated to obtain the expression for K given in (5).

$$K = \left[\frac{p'(100 - p')/n}{\sum_{i=1}^{N} (p_i - \bar{p})^2 \ (N - 1)}\right] = \frac{\sigma_{t'}^2}{\sigma_0^2}. \tag{5}$$

The K values computed in this manner for each of the work classifications studied are given in Table I.

* This formula applies to random samples. The slight effect of the stratification of the samples used in this study has been neglected.

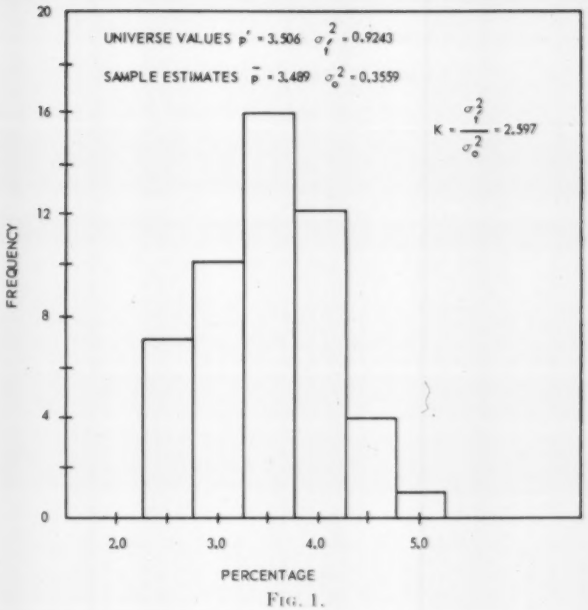

FIG. 1.

Analysis of the Results

The K values listed in Table I have been placed into three groups on the basis of an analysis of the nature of the work classifications. The first group contains only those classifications in which the crews worked independently of each other. The second group, containing classification H only, was the miscellaneous work classification which was made up of a number of different activities. In some of these the crews worked independently of each other, while in others the activity was common to all crews. An example of the latter is the formal rest period which was taken at the same time by all crews. The third group of work classifications was such that the crews almost always worked in unison. For example, work classification I consisted of clean-up work, an operation generally performed by all crews of workers at the end of each shift. As stated above, the grouping used in Table I was based on the nature of the work classifications. In Group I, those work classifications were included in which the crew activities were completely independent, in Group III the crew activities were for practical purposes all the same, while in Group II a mixture occurred. Stated in statistical terms, the crew activities in Group I were statistically independent; in Group III, perfectly correlated; and in Group II, partially correlated.

Examination of Table I indicates that the K values are roughly the same for all work classifications in the same group, as suggested by the above discussion. The validity of this hypothesis will be assessed below.

Definition of a "Crew"

The above results suggest defining K as the average number of independent crews of workers per observation,

TABLE I

Results of Work Sampling Experiment

Work Classif.	Group Desig.	p'	$\bar{p}$	$\bar{p} - p'$	Z	$\sigma_{\bar{p}'}$	σ_0	K	95 Percent Probability Interval for K	$\bar{K}$
A	I	43.549	43.417	−0.132	−0.644	2.5917	1.4746	3.0747	2.29–5.10	3.19
B		14.406	14.371	−0.035	−0.241	1.8355	0.8969	4.1881		
C		7.464	7.610	+0.146	+1.343	1.3737	0.9077	2.2904		
D		3.717	3.588	−0.129	−1.649	0.9889	0.6149	2.5854		
E		3.506	3.489	−0.017	−0.223	0.9614	0.5966	2.5973		
F		4.131	4.133	+0.002	+0.002	1.0402	0.5545	3.5187		
G		1.188	1.159	−0.029	−0.647	0.5663	0.2794	4.1083		
H	II	17.367	17.274	−0.093	−0.439	1.9802	1.4962	1.7464	—	1.75
I	III	2.247	2.564	+0.317	+2.837	0.7747	.9437	0.6739	0.70–1.55	0.96
J		2.425	2.344	−0.081	−0.697	0.8041	.7271	1.2412		

the average being over all sample observations in the study. Unfortunately, a count of the number of crews of workers was not made in the all-day time study from which the experimental universe was taken. However, knowledge of the operation indicated that in almost all cases the crews consisted of two men each. Now, in the 50 Work Sampling studies of the experimental universe, the average number of workers per observation was 6.59. Assuming the value of two workers per crew to be correct, this would give an average of 6.59/2 or 3.29 as the average number of crews per observation in the Work Sampling studies. This value agrees quite well with the observed $\bar{K} = 3.17$, the average K value for Group I work classifications in which the crews worked independently of each other. Similarly, the above definition would lead to a theoretical K' value of 1.00 for Group III in which the crew activities were essentially the same. Here again the agreement with the observed $\bar{K} = 0.96$ is good.

The above theoretical K' values furnish a convenient basis for testing the null hypothesis that all work classifications in the same group have a common K value equal to 3.29 for Group I and 1.00 for Group III.* This hypothesis was tested by computing a 95 per cent probability interval for K as given in Table I.† Comparison of this interval with the observed K values indicates one value on the limit and one value beyond the limit. Additional calculations show that all values are contained in a 98 per cent probability interval. On this basis one cannot reject the null hypothesis.

To summarize, K is defined as the average number of "crews" of workers per sample observation, a "crew" being one or more workers performing a task in which the activity of any crew member is dependent upon the activity of others in the same crew, while the crew activities are independent of each other. One can also consider the product (nK) as the total number of crews observed in the study; it is actually this value which would be used in computing the standard error of the work sampling estimate. It should be emphasized that this definition has been verified only for the type operation studied in this paper.

The successful application of this definition depends on two factors. First, proper breakdown of the operation into groups of work classifications having a common K value; and second, a reasonable estimate of the K value for each group of classifications in the study. Preferably, this breakdown should involve only two groups, one in which the crew activities are essentially independent of each other, and the other in which the activities are common to all crews. For example, the work classifications in the experimental universe studied in this paper could have been included in only two groups instead of three by redefining work classification H so that part of it would fall in Group I and part in Group III, thereby eliminating Group II.

Investigation of the Accuracy of the Work Sampling Estimates

The second question raised regarding Work Sampling applied to a variable labor force pertained to the accuracy of the estimates, i.e., are they unbiased estimates of the universe values. This question was investigated by testing the null hypothesis that the mean of the distribution of the 50 Work Sampling study estimates was equal to the mean of the experimental universe for the activity in question. For example, referring to Figure 1, we want to determine if the mean of the observed distribution, $\bar{p} = 3.489$, differs significantly from the universe mean $p' = 3.506$. This hypothesis was tested with the following statistic denoted by Z.

$$Z_j = \frac{\bar{p}_j - p'_j}{\sqrt{\frac{p'_j(1 - p'_j)}{Nn\bar{K}}}}$$

* Since Group II is composed of an unknown mixture of correlated and uncorrelated crew activities, no theoretical K' value is possible.

† $K = \sigma^2_{\bar{p}'}/\sigma^2_0$ is the ratio of a constant $(\sigma^2_{\bar{p}'})$ to a sample variance which has a Chi-square distribution, since the random variable p_i is very nearly normally distributed. Confidence intervals on σ^2_0 were used to give a corresponding confidence interval for K.

where:

$\bar{p}_j$ = the grand mean of the 50 Work Sampling percentage estimates of the occurrence of the j^{th} work classification

p'_j = the true percentage occurrence of the j^{th} work classification in the experimental universe

n = the number of observations in one Work Sampling study (366)

N = the number of Work Sampling studies (50)

$\bar{K}$ = average number of effective samples per observation for the group of work classifications of which "j" is a member.

Assuming the Z statistic is normally distributed and that the null hypothesis stated above is true, the distribution of the ten sample Z values should conform to the expected frequencies dictated by the Normal distribution function. This comparison is shown below.

Range of Z Values	Expected Percentage Occurrence	Observed Percentage Occurrence
±1	68.3	70
±2	95.4	90
±3	99.7	100

The agreement between the expected and observed percentage occurrence offers no reason for rejecting the null hypothesis and therefore it is reasonable to conclude that the Work Sampling percentage estimates obtained in this experiment are unbiased.

Sample Work Sampling Study

It is interesting to note that the product of nK, (number of observations times the average number of crews per observation) is the number of crews observed in a Ratio Delay study. This nK value is the denominator in the formula for the variance of the sampling error. Thus this variance varies inversely as the square root of the total number of crews observed.

If the nature of the work classifications was such that they did not necessarily have to occur simultaneously with each other, then the number of total crews observed could be different for each work classification. This situation is illustrated in Figure 2, a hypothetical Ratio Delay study of only three observations containing five Work Classifications. In this table, each line or row represents one independent crew and there are several rows for each observation. Each check mark represents one operator and the circled values are the total number Work Classification crews per observation.

Two of the classifications, D and E, were performed by crews, but not necessarily simultaneously and thus the K values of D and E are different. The Classifications B and E, have the same percentage delay but their K values and variances are different.

Obser. No.	Work Classifications A	B	C	D	E	No. Operators Per Crew
1	√					1
1	√					1
1		√				1
1		√				1
1			√√			4
			√√			
1				√	√	2
1				√	√√	3
Total No. of Crews	(2)	(2)	(1)	(2)	(2)	
2	√					1
2		√				1
2			√√√			3
2				√		1
2				√√	√	3
Total No. of Crews	(1)	(1)	(1)	(2)	(1)	
3	√					1
3		√				1
3		√				1
3			√√√			3
3				√	√	2
Total No. of Crews	(1)	(2)	(1)	(1)	(1)	
Total Operators	4	5	10	6	5	30
Total Crews	4	5	3	5	4	

$$K_A = \frac{4}{3} = 1\frac{1}{3} \qquad p_A = \frac{4}{30} = .133 \qquad \sigma^2_A = \frac{(p)(1-p)}{nK} = .0288$$

$$K_B = \frac{5}{3} = 1\frac{2}{3} \qquad p_B = \frac{5}{30} = .167 \qquad \sigma^2_B = \frac{(p)(1-p)}{nK} = .0278$$

$$K_C = \frac{3}{3} = 1 \qquad p_C = \frac{10}{30} = .333 \qquad \sigma^2_C = \frac{(p)(1-p)}{nK} = .0739$$

$$K_D = \frac{5}{3} = 1\frac{2}{3} \qquad p_D = \frac{6}{30} = .200 \qquad \sigma^2_D = \frac{(p)(1-p)}{nK} = .0320$$

$$K_E = \frac{4}{3} = 1\frac{1}{3} \qquad p_E = \frac{5}{30} = .167 \qquad \sigma^2_E = \frac{(p)(1-p)}{nK} = .0347$$

FIG. 2. A HYPOTHETICAL RATIO DELAY STUDY

Summary

Work Sampling can be successfully applied to long cycle variable labor force operations, however, special attention must be given to the assessment of the confidence of the results. It has been demonstrated in this study that the effective sample size for the operation studied, i.e., small crews of operators working simultaneously on large aircraft assemblies, can be approximated by the number of independent crews of workers observed.

This study points out the effect of correlation of worker activity on the sampling error of the Work Sampling estimates and suggests that care must be taken in stating the reliability of the results. Attention should be given to this problem in other areas; one should not conclude that simultaneous observation of a group of workers yields independent random observations even though the workers are engaged in seemingly separate tasks. Future mathematical analysis will be required to obtain a more generalized treatment of this problem.

A New Conceptual Approach in Work Study

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In Great Britain the practice of Work Study, which is the general equivalent of industrial engineering in the U.S.A., follows a program, and consequently uses concepts, mainly derived from the practice of C. E. Bedaux. Bedaux was concerned with everyday planning and control systems which relied heavily upon time standards derived by stopwatch timing in a manner first proposed by F. W. Taylor, but to which Bedaux introduced the practice of rating. At a later date the work of the Gilbreths began to permeate Bedaux' practice so that today Work Study has been divided into

1. Method Study, relying mainly on Gilbreth techniques.
2. Work Measurement, consisting of stopwatch and synthetic timing techniques.

This dichotomy is convenient although it does not fit, for instance, the work sampling techniques of ratio delay and memomotion. The general approach to a practical problem would be to derive the 'best' method by Method Study and when this is accomplished, although not always, apply Work Measurement.

In considering this approach it is useful to examine the program of F. W. Taylor in what he called Time Study, but which is substantially that covered by Work Study today. The genius of Taylor (the centenary of whose birth is celebrated in 1956) is not always appreciated, but it is shown in his method of Time Study consisting of three distinct parts:

1. An experimental investigation of a process to derive the best method of performing it which was then standardised.
2. The timing by stopwatch of the performance of that job by a *selected, trained and highly motivated* worker. The timing was made on elements of the work cycle. To the measured times were added allowances for stoppages due to material shortage, sharpening tools, etc. and an allowance for the physical fatigue incurred in the job.
3. The subsequent analysis of these element times to form a system of synthetic time values.

The first section forms what is called Method Study, which certain followers of the Gilbreths equate with Motion Study (25). This is a misconception of the term, although it may well be generally true in practice. The first section implies the use of any scientific discipline in betterment of the method of work: this is an extremely important proviso for many modern work conditions in which the Gilbreth techniques are of limited application. Taylor was an engineer, which probably biased his outlook, but his concentration on metal cutting experiments which, *in that context*, were technically more important than Gilbreth's techniques shows the necessity to adopt a wider approach than that given by motion study. The Gilbreths extended the first section of Taylor's Time Study to the general ordering of work depending upon physical effort at normal temperature under conditions in which there were no outstanding psycho-physiological restrictions. This was so fruitful in results that the debt of industrialists to the Gilbreths is overwhelming.

The second section comprises what is now time (small 't') study but which is better called stopwatch (rating) study. Taylor established rest allowances for physical fatigue using *experimental* methods and an insight into work physiology which is extraordinary for its modern approach. In the Schmidt experiment he deduced that under load the worker should run, and that a rest allowance of $\frac{58 - 42}{42} \times 100\%$ was necessary after each work cycle. This is in general agreement with modern work such as Prof. G. P. Crowden's prewar results (10) and Prof. E. A. Muller's recent results from Dortmund (21). However, in the practice of Bedaux and his followers these fatigue allowances degenerated into a tabular form which is given in many textbooks on time study. The tables are not consistent in the factors for which they make allowance nor in the values given. These discrepancies prompted investigations reported below from which the writer has developed some new concepts which, it is suggested, form a basis for research and development.

The third section of Taylor's Time Study has now been widely developed in the field of Predetermined Motion Time Systems such as M.T.M., Work Factor and Basic Motion Time Study.

Modern Investigations

Practitioners in Great Britain are not satisfied with the status of present fatigue allowances, and American writers, such as Abruzzi (1) and Gomberg, have been openly

critical. Two investigations have been proceeding in England, one by Dr. N. A. Dudley at Birmingham University and the other by Dr. R. M. Belbin and the writer at the College of Aeronautics, Cranfield, into general work delays in the former and into fatigue (C.R.) allowances and rating in the latter case. Work sampling technique studies of actual worker behaviour were made in both cases, and the finding of Dr. Dudley (11), with which the Cranfield study agrees, was that the workers' *voluntary stoppages* were at or below a level of 10%, and the work cycle rating remained substantially constant during the day. The oft quoted 'fact' that the shape of the production vs. time curve (with its 'warming up' and 'fatigue falloff' periods) was caused by physical effort factors was disproved—at least for the large number of operations studied.

The shape of the production-time curve seems to be accounted for by stoppages from material shortages and machine holdups occurring and personal time being taken at those periods. These results are in line with that reported by Abruzzi (1) and would seem to be at variance with industrial engineers' present concepts. It must be recognised however that right answers are probably being obtained in industry for wrong reasons. As now practised, an observed stopwatch time is corrected by two numerical factors *at the same stage of the calculation*: the time is normalised to 60 on the Bedaux scale (this 'normalising to 60' procedure is now being gradually abandoned in Great Britain) and the fatigue (C.R.) allowances are applied. Obviously a higher than average rating correction can be offset by a lower than average fatigue (C.R.) allowance correction and this seems to be found in practice. If, however, practitioners want their fatigue (C.R.) allowance values to accord with *discoverable behaviour* of workers then rating values may have to be altered.

This may have an important side effect on Predetermined Motion Time Systems (P.M.T.S.) as, despite their claim for 'accuracy', fatigue (C.R.) allowances have to be added to analysis values. If, as the studies reported above suggest, 10% would cover voluntary stoppages then the present P.M.T.S. values would seem to be low.

Present Fatigue Tables

It is necessary to comment on the present state of fatigue (C.R.) allowance tables. The writer has made a survey (29) of these and the factors applied may be generally divided under headings of

(a) Physical effort
(b) Posture
(c) External Environment (temperature, humidity)
(d) Protective Clothing
(e) Eyestrain
(f) Attention
(g) Personal and Hygiene Requirements
(h) Monotony

This is essentially a rational division but it does not accord with ergonomic thought. The writer suggested (29) a division into four factors only for purposes of research

(a) Physical effort at normal temperatures (posture being included in this).

(b) Heat stress: in which physical effort, posture, external environment, protective clothing and attention would have to be considered.

(c) Psychomotor (perceptual) factors: in which psychological factors such as those now under headings of attention and monotony would be considered with new factors. A restatement of terms is especially needed under this heading.

(d) Social factors: in which monotony and personal hygiene would be considered along with new factors such as 'possibility of talking to neighbours'.

These headings are not necessarily independent of each other and indeed interaction between (a), (b) and (c) is known to occur. However the division does lead to sectors of method study which can be pursued relatively independent of each other and to the formation of situation stress indices.

The present fatigue (C.R.) allowance tables seem to allow for three different purposes

(a) rest (voluntary stoppages) following along rational psychophysiological lines

(b) as correction factors to make predicted production from time study accord with actual production

(c) as job evaluation factors to give differential payments to workers on the same basic labour rate but performing different types of work.

It is impossible (in the writer's submission) to sort out these different purposes in a scientific investigation of the validity of these allowances. One can only study workers' behavior ('fatigue' cannot be measured) and the studies of behavior reported above do not support a concept that rest pauses follow any pattern as presupposed by tables. It is not within the competence of the writer to suggest discontinuing present industrial practice as it must be recognized that, in the social context in which these allowances are applied, the worker expects to be given rest allowances following along some sort of pattern as now used. In such a case it is indeed reasonable to continue present practice although it may well revolt the academic mind.

The divisions made by the writer for a scientific basis for allowances based on ergonomic considerations does lead however to consideration of work in certain different sectors of study in order to reduce the stress (somehow defined) on the worker. These sectors may well involve scientific disciplines which, at the moment, are distinct. In order to maximize production it is, at the lowest evaluation, uneconomic to give large fatigue (C.R.) allowances because of job stress. The reasoning here follows along the lines.

(a) if the rest is actually taken and is needed, labor and indirect costs are increased and production from given factory facilities is below maximum capacity

(b) if rest is not taken, labor cost is increased

(c) the likelihood of a long training or accommodation period is present if work requires large allowances.

For such reasons modern practitioners conduct method studies of the process initially to derive a better method before the job is timed. This method study may be of technical aspects of the process (such as in the metal cutting experiments by Taylor) but in present general practice the study follows along lines dictated by Gilbreth motion study. This is only one of the sectors in which stress arises and it is necessary to consider the others. It may be possible to set up stress indices of the work situation in these sectors determined by objective measurements in some cases or even subjective examination (such as with motion study) of the work situation in others. In order to decrease the stress on the worker the lines along which alterations in the job must be made are then indicated by the form of the index or of the principles of the examination. In making this proposal it must be recognized that a great difficulty will be removed in such a 'relative' approach rather than in an 'absolute' approach as at present. The main difficulty in giving fatigue (C.R.) allowances at present is that of defining the 'average worker'. It is the writer's contention that workers selected and trained for a job should not need the large allowances often found as, if they are not suited to the conditions of work, they should be shifted. However if a 'relative' approach be adopted, the strain of work will be decreased in a manner which it is reasonable to assume will be common for all workers.

These aspects of study will now be considered separately: they fall conveniently into four sectors although others could be proposed as subdivisions of psychomotor study.

Physical Effort Study

At the time of Taylor (75 years ago) much physical effort was exerted in working under normal temperature conditions. The principles of motion enunciated by the Gilbreths have been effective in reducing physical effort so that, for *repetitive work* now found in industry, the main physical effort stress that does arise probably results from bad posture, which requires change of position for relief. This is not to say that workers do not feel tired but in physiological terms this does not arise from discoverable lactic acid formation arising from muscle action: the effort expended is well within the recovery capacity of the human organism. It may seem a verbal quibble but such tiredness is probably motivational or concerned with the psycho-physiological state of the nervous system.

It is reasonable to suggest for practical cases that stress from physical effort can be reduced following motion study practice. This should be reinforced by the latest physiological and human anatomical knowledge because the tenets of motion study are not rigorous and sometimes have the situation both ways: they have been criticized destructively by physiologists but in practice are an admirable 'packaged' system suitable for technicians.

The stress reduction under this heading therefore follows along generally accepted lines. Although these lines are mainly descriptive, they are quantifiable and were used in such a way by the Gilbreths. Thus the object of study using micromotion, flow, flow process, string and travel charts is to reduce distance moved or the number of therbligs involved (principally the 'unproductive' ones).

Heat Stress Study

The previous section employed the descriptive system of stress reduction of the Gilbreths but in the present case a numerical value can be assigned to the stress of the working conditions.

Heat stress results in lowered physical effort being exerted, decreased psychological performance and heightened accident rate. The present C.R. allowance tables (29) are useless as a basis for allocating rationally rest allowances for heat or for reducing heat stress. The physiological response of the human organism to hot conditions takes the form of increased sweating, pulse rate, body temperature, etc. and these responses have been used in deriving two stress indices which seem to be useful in this context.

(a) a sweat index P4SR (Predicted 4 hour sweat rate) deduced by McArdle and his associates at the National Hospital, London towards the end of the war (26).

(b) a body heat gain index proposed by Belding & Hatch (3) following the development of mathematical formulae by Haines & Hatch (16).

Both indices are determined from nomograms but the latter can be easily calculated from the formulae. They require knowledge of the following determinable factors of the work situation

(a) globe (black bulb) temperature
(b) dry bulb temperature
(c) wet bulb temperature
(d) air speed
(e) metabolic rate of worker (physical effort measure)
(f) clothing conditions.

Certain necessary simplifying assumptions are made so that factors not taken into account include

(g) mental effort, which inhibits sweating and so adds to the heat stress
(h) posture, which alters sweat pattern.

Curves of P4SR are shown in Fig. 1 determined along systematic lines. Such an ordered plotting when used with measured quantities at the work place shows the direction in which alteration in the work conditions must take place to reduce the stress index. This does not imply that equal decrement of index at various points of the scale means equal *feeling* decrement but this is not important here.

The Belding & Hatch Index is primarily an engineering concept: objections may be raised by physiologists to its use but it presents an extremely useful approach in the present context.

In considering both indices it is necessary to obtain a time integral of the stress in each position occupied during

the work cycle. The Institute of Preventive Medicine, Leyden, have carried out studies in this manner in industry using the Haines & Hatch formulae and close correspondence has been reported between their measurements and predictions (4).

In many work situations the important effect of infrared radiant heating of the worker is unappreciated by technicians. This effect comes into the makeup of the indices through the globe temperature and such a stress raiser can be reduced in effect by reflection insulation.

In hot conditions acclimatized workers can endure high sweat losses (say 3 liters in 4 hours) but work of psychologists (18) suggests that psychological performance falls off much earlier (around 1 liter in 4 hours).

The writer has derived formulae giving the necessary technical changes in environmental conditions for a required change in Belding & Hatch Index (31). In some cases the environmental conditions cannot be improved in which case decreased physical effort (metabolism) must result in order to maintain a constant index value: such a decrease is predictable from the formulae.

As heat stress depends upon a time integral of stress raising conditions which sometimes occur whether the workers be working or not, it may be advantageous to air condition workers during rest pauses (7). Cold working conditions can be treated along similar lines.

Insofar as physical effort enters into the heat stress situation through metabolism, the Gilbreth techniques have a limited application to this sector. Fig. 1 shows the important effect of interaction between metabolism and the other heat raising factors.

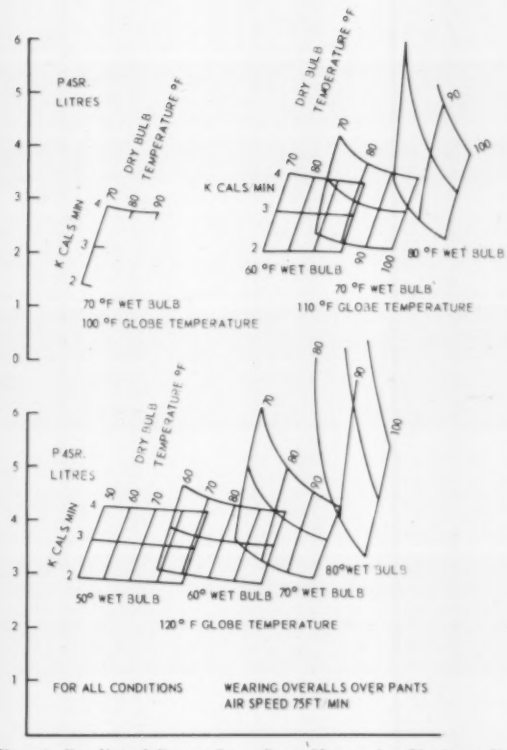

FIG. 1. Predicted Sweat Loss In 4 Hours for Various Conditions of Temperature and Work.

Psychomotor Factor Study

This field is relatively undeveloped and stems principally from work of ergonomics teams in the military forces during the war. It has been shown by hard experience that much conventional civilian and military equipment is grossly defective in that the limitations of the workers in controlling the equipment have not been considered (6). A mechanistic approach cannot be adopted in such cases and the approach in many cases must be experimental although certain principles are being developed in U.S.A. and Great Britain (5).

Typical instances of industrial work in which these factors are high are visual inspection processes and manual telephone exchange operation. In such cases the nervous system of the worker is mainly involved rather than the muscles and it is convenient to consider three aspects in the process

(a) in obtaining sensory data from the work situation (the display) through one or more of the sense organ modalities (visual, audile, kinaesthetic, etc.)

(b) the treatment of this centrally in the brain or lower levels of the nervous system

(c) the actuation (or inhibition) of muscular response following this treatment.

Experimental work following these concepts is taking place widely at the moment. Information theory terms are often used in this context (13) which are helpful conceptually but at the moment still require development for experimental use. Investigation of performance using multiple dials to which response has to be made, and of dial watching tasks requiring vigilance over long periods of time has led to a better understanding of corresponding industrial work situations in order to design a better work load for the worker. Mackworth (19) has recently reported some findings in this field but it is important to remember that such laboratory test results always require industrial validation. An important contribution of Mackworth and his fellow workers would seem to be a redefinition of the problems which technicians now loosely class under headings of monotony and attention.

In this sector, but distinct from the preceding discussion are situations to which statistical queueing theory apply: these occur in multi machine minding situations and in conveyor belt working. In the former case much work has been done to increase productivity using statistical predictions (otherwise indices) to give optimum machine allocations to workers (12, 20, 22). In the latter case the study of conveyor belt working is usually carried out using the stopwatch (rating) technique. However it is easily shown statistically that the work condition differs greatly between conditions of arrival of work at the work place (Fig. 2) and also whether a work 'bank' is formed. The

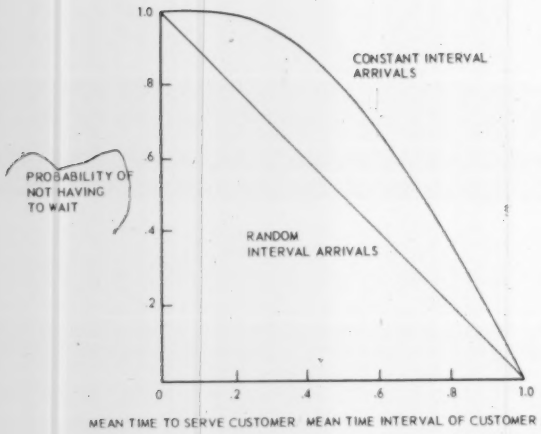

FIG. 2. Queueing Theory Application to Conveyor Belt Work.

older the worker the greater is his dislike (in general) of conveyor belt pacing and Guest in the U.S.A. (14) and Belbin in Great Britain (2) have shown that psychological strain results in such conditions. The writer considers the formation of a stress index for such conditions is possible based on queueing theory using 'probability of not having to wait' (given in Fig. 2) as the index. It is hoped that this can be applied in practical cases following experimental validation. Conrad (8) has shown in a practical case that conveyor belt work cannot be assigned on a basis of performance mean time alone, the performance variance having to be considered as well; this is shown theoretically by Fig. 2.

A study system falling into this sector has been proposed by Crossman (9) which he terms perception study. In this the various sense modalities entering into work are considered together with the overt movements of the body. This study is carried out along descriptive lines using a chart method of analysis at the moment although it is suggested that information theory should be applicable here. At the present stage of development, Crossman's analysis would appear to be limited to certain sections of psychomotor study.

The psychomotor sector is the most unsatisfactory at the moment because it is relatively undeveloped and also inefficiency is present in work situations without technicians or workers realizing the basic causes or even that inefficiency exists. However, this situation may be remedied quickly because of the importance of these factors in the military field and the extension of solutions from there to civilian practice.

Social Factor Study

These may be the least subject to quantification but, to a certain degree, stress in a given situation is relieved by the social action of the workers themselves or through their union representatives. There does exist in this field unconscious causal factors such as those forming the field of study of the Tavistock Institute of Human Relations in Great Britain (17) and of the Ann Arbor, Michigan, investigators in U.S.A. but these are difficult to analyze. It is considered that some of the reported production increases from these sources *could be* explained by technical or other considerations. The use of production indices purporting to show the effect of better social relationships is fraught with dangers if rigid controls, difficult to apply in industry, are not present: small technical changes can often result in greatly increased production and regrettably the fallacy post hoc, propter hoc is often present.

The importance of such studies (15, 17, 27) cannot be overestimated as showing the understandable fact that workers are human but also that changes may be reflected in increased production.

At this stage the techniques of social study are mainly impressionistic and method study in this sector would be descriptive in a like manner to motion study. However there are possibilities of quantifying some aspects of worker behavior to deduce causal factors as shown in a study of the writer (30). Care should be taken in extending the findings of this study into a generality as it was based on studies of two groups of women only, each performing different types of work. In this, the ratio delay technique was used to quantity behavior under headings such as

(a) Working	(i) talking	(ii) not talking
(b) Not Working	(i) talking	(ii) not talking

One group was engaged on an unpaced press operation task requiring visual attention and the other on paced conveyor belt packing of sweets not generally requiring visual attention: the talking level in the latter group was over double that in the former but they did not stop work to talk whereas the former group did. People have a desire to look at each other while talking and it is suggested tentatively that, in a job requiring visual attention, a social stress exists as talking is interfered with.

Much work remains to be done before even a descriptive form of study is available for social factors, as impressionistic study techniques such as attitude studies are unreliable as an indication of worker behavior—the only worthwhile criterion.

An interesting point of interaction of social factors with motion study occurs in the modern practice of Job Enlargement (15). Too logical an application of Gilbreth motion study principles leads to work which is boring for many people: this is being counteracted by combination of simpler jobs to which rigid motion study principles would otherwise lead.

Conclusion

It has been suggested as a result of studies principally aimed at deducing fatigue (C.R.) allowances in time study that a new conceptual approach be directed at method

study of human behavior. To date, motion study has proved pragmatically useful and profitable in the field of human method study. Motion study is only one of the four (or more) sectors into which human method study can be shown to yield profitable results, the others including those termed here heat stress study, psychomotor (perception) study and social study. Numerical indices have been developed in the case of heat stress study in order to show the effect of changes in factors which influence the stress and it may be possible in certain cases of psychomotor study to produce similar indices based on statistical analysis. In the case of social study and in certain fields of psychomotor study, it is thought that descriptive study is possible only, in a similar form to the motion study principles enunciated by the Gilbreths. Such sectors of study require much further development and research but the conceptual framework proposed may lead to some co-ordinated progress being made by parties who, at present, do not view their work as related. In Great Britain the Ergonomics Research Society (founded 1949) is providing a co-ordinating group in this field although their interest is scientific and not aimed at providing pragmatic solutions. The framework proposed above applies only to human conduct in association with machinery in production processes and not to technical method study (outside of human control) to which field increasing attention is being directed in automation.

Acknowledgments

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Sequential Decisioning Technique for Optimization of Complex Systems

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Significant progress has been made, in recent years, in the development of the methodology of optimization in circumstances where the technology of the system being studied is known. Some analytic techniques which come under this classification are:

1. Linear programming (1).
2. Assembly line balancing (20).
3. Inventory control (22).
4. Queueing theory (10).

Many management decision situations, however, are too complex to be handled by analytic techniques, and often non-analytic methods for finding optimal or near-optimal solutions have to be used. An example of a non-analytic technique is the Monte Carlo method or operational gaming (8).

Basic to this technique of operational gaming is the idea that the operation of the system under study can be simulated as a game which can be played on a computer or on paper. A limitation of this method is that the rules according to which the game is played have to be precisely defined and have to bear close resemblance to the operation under study; otherwise the results might not have any validity. The operational gaming approach, therefore, can be effective only in circumstances where the rules which govern the system under study are known.

Theoretically, every system behaves according to certain rules, and if these rules are known, it should be possible to find the conditions under which the system could be operated so as to optimize the response (outcome). However, the fact is that in many situations the rules which govern the system are not known, or if known are too complex to be amenable to mathematical manipulation or operational gaming approach, thus necessitating the use of empirical or experimental techniques.

Response Surface Technique

If the response Y of a system depends upon levels $(x_1, \cdots, x_k)$ of k factors, such that the underlying functional relationship $Y = \phi(x_1, \cdots, x_k)$ is not known, a naive way of finding the set $(x_1^o, \cdots, x_k^o)$ of levels of these factors which maximizes the response is to use what is known as the grid method. This involves finding empirically the response for all sets of levels of factors in the region of interest (factor space) and then picking out the set $(x_1^o, \cdots, x_k^o)$ for maximum response. It is easily seen that the number of trials necessary for such a method increases considerably as the region of interest and the number of factors increase. For example, if a factorial grid were employed with three factors ($k = 3$) and ten levels for each factor, the number of trials required would be $10^3 = 1{,}000$.

The method commonly employed in industry is to vary one factor at a time, keeping all other factors constant. This method does not necessarily lead to an optimal response, as is illustrated in the two factor case by the nature of contours of response levels shown in Figure 1. If the experimenter starts out from point P and varies x_1, keeping x_2 constant, he will achieve increasing response until he reaches point A. Any further increase in the level of x_1 would result in decreasing response.

If at point A he keeps x_1 constant and varies x_2, he will achieve decreasing response and will probably conclude that A is the point of maximum response. The fact that A is on a ridge of rising response is very likely to miss his attention. It is therefore obvious that a methodology for exploring the path of steep ascent to the maximum response in an unknown region is required.

One efficient technique along these lines has been suggested by G. E. P. Box, a British statistician working with the I.C.I., Ltd. This approach is actually a technique of experimental design and uses the method of multiple regression. Essentially, the technique involves selecting a subset of k dominant controllable factors from the whole set of $n (n \geq k)$ factors which are believed to affect the response being optimized, and conducting a series of sequential experiments in the laboratory or under operating conditions. Examples of the response to be optimized include the cost of manufacture, the purity of a product, the yield of a process, or the gain from a combat operation. The technique attempts to improve the response by simultaneously varying the levels of dominant factors in successive trials, and at each trial the information obtained from the immediately preceding set of experiments is used to determine the path of steepest ascent. This procedure is continued until the levels of factors for what appears

to be the peak response are determined. Further exploration is then made in the neighborhood of this near-stationary response to see if the response can be improved.

Since the technique involves "feeling one's way" in an unexplored region, results can be obtained efficiently if the dominant controllable factors and the region of interest (defined by the upper and lower bounds for each dominant controllable factor) can be designated from a general idea of the system available from past experience. Work can be minimized considerably by judicious choice of factors which are really dominant.

Factor Dependence

A brief discussion of controllable and uncontrollable, dominant and sub-dominant, factors seems to be in order here. A factor is controllable if its level can be chosen at will by the experimenter within some bounds. Some factors which may appear uncontrollable might really be partly controllable. For instance, for a system engaged in bombing enemy targets, weather might at first seem to be an uncontrollable factor. However, the time of the bombing mission can often be selected so as to control the weather factor. On the other hand, a sudden change in weather after the bombers have left the base for the bombing mission is a factor which cannot be controlled (11).

Some factors which may appear to be sub-dominant in one subspace of the region of interest might become dominant in another subspace. Thus, heat due to friction, which is a sub-dominant factor for planes flying at ordinary speeds, becomes a dominant factor at higher speeds.

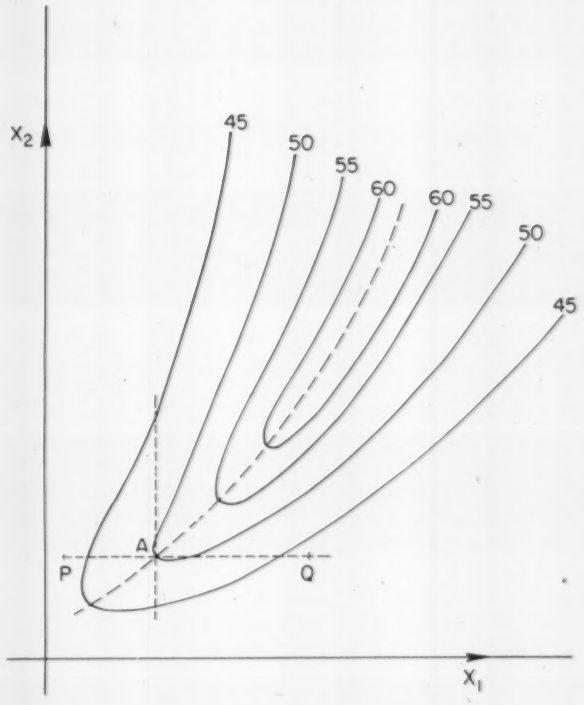
If a factor is recognized as dominant and uncontrollable, it may not be worthwhile attempting to control the system by adjusting the levels of sub-dominant factors.

In some cases, where two factors x_1 and x_2 appear to be dominant, it might be that actually it is the ratio $\frac{x_1}{x_2}$, or $\frac{x_1}{x_2}$ and x_1, or some other function of the ratio of these factors that is of importance.

As another example of factor dependence, consider the general case of non-linear programming where the objective is to minimize the total cost of manufacture $\Sigma_i d_i x_i$, and where the unit cost d_i of an activity i varies, in some known or unknown way, with the level x_i at which the activity is operated. At first, it might appear that the dominant factors on which the total cost of the program depends are the quantities of materials consumed, labor, and other inputs; however, for our purpose, the dominant factors are x_i's.

How the Technique Works

If a system being investigated is actually operating (the experiments could also be performed in the laboratory or on a pilot scale), the levels of dominant factors and of the response are noted. Alternatively, if an idea of the levels of dominant factors for near-optimal response is available from past experience, the system is operated at these levels and the response is recorded. The levels of factors are then changed simultaneously and the experiment repeated until enough observations are made to enable a polynomial (usually of the first or second degree) to be fitted to the data obtained from this sample. The equation to this polynomial gives a clue to the path of steepest ascent for improvement in the response.



RISING RIDGE RESPONSE SURFACE CONTOURS

FIG. 1.

Thus if $(1, \cdots k)$ dominant controllable factors are involved in the system and a polynomial of the first degree,

$$Y = a_0x_0 + a_1x_1 + a_2x_2 + \cdots + a_kx_k^*$$

is fitted to the experimental data of observed response and levels of factors, we have, on taking partial derivatives,

$$\frac{\partial Y}{\partial x_1} = a_1$$

$$\frac{\partial Y}{\partial x_2} = a_2$$

$$\vdots$$

$$\frac{\partial Y}{\partial x_k} = a_k$$

* Here $x_0 \equiv 1$ is introduced for mathematical considerations. It might be noted that any of the coefficients of x's might turn out to be negative or negligible.

Now $\frac{\partial Y}{\partial x_j}$ $(j = 1, \cdots k)$ gives the gradient of the fitted polynomial in the direction of j-th factor. This means that for improving the response rapidly in the neighborhood of the fitted polynomial, the factors $1, 2, \cdots, k$ should be changed simultaneously in the proportion of $a_1 : a_2 : \cdots : a_k$ experimental units.

The levels of factors are then changed sequentially in steps until it is obvious that extrapolation has been carried too far and that the originally fitted polynomial no longer provides a good fit. A fresh set of experiments is then conducted and the sequential process repeated until what appears to be the peak response is reached.

Limitations of the Technique

The technique as it is developed today explores only the region for a local maximum. Cases for finding the absolute maximum where two or more maxima exist do not seem to have been treated.

The technique seems to be of questionable value in situations where some dominant factors cannot be controlled, that is, their level cannot be chosen at will. In such a case, every significant shift in the level of any dominant uncontrollable factor may change the system and entail making fresh explorations.

Systems to which the technique can be applied successfully must necessarily have small errors in the measurement of response, so that significant changes in the level of response caused by changes in levels of dominant factors can easily be detected.

Where Applicable

Applications of the technique have already been made in a number of investigations in the chemical industry for maximizing the yield or purity where the dominant controllable factors include temperature, pressure, duration of reaction, and type and concentration of reagents used.

The methodology involved in the technique seems to suggest strongly that the technique would be effective in most continuous process industries like the manufacture of paper, soap, cement, steel, food processing, and oil refining, to name a few. The method could also be extended to some other fields of management sciences and to military applications.

An example of the application of Box's technique for exploration in the chemical industry is given in (9). An illustration in the military field is given below. Most of the data and ideas for the illustration have been taken from a paper by Flood (11) although the method of solution presented here is different.

Illustration

Problem Statement

This example concerns the analysis of a system entrusted with the task of bombing enemy targets. For every bombing mission (z), the attacking unit incurs a cost $C(z)$ which is composed of elements like:

1. Loss in aircraft and men.
2. Operating costs (fuel, etc.).

The worth $W(z)$ of the bombing mission (z) depends upon the destruction caused to the enemy target. Within limits, the greater the number of bombers sent out on a mission, the greater the destruction. Also the lower the flying altitude, the greater the precision of bombing and therefore the greater the worth. However, as the flying altitude is decreased, the enemy is likely to inflict heavier losses on the attacking bombers which results in increased cost to the attacking side.

If unlimited resources were available, the objective would be to maximize the worth of each mission regardless of cost. However, as is usually the case in prolonged wars, resources have to be conserved; hence, the objective in this case is to find an optimal operating condition for maximum gain $G(z)$, where:

$$\text{Gain } G(z) = \text{Worth } W(z) - \text{Cost } C(z)$$

It might be noted parenthetically that other objective functions like $\frac{\Delta G(z)}{\Delta C(z)} \geqq$ a constant could also be used. The choice of the objective function will depend upon the situation.

To simplify the illustration, it is assumed that $W(z)$ and $C(z)$, and therefore $G(z)$, depend upon the following two dominant factors:

1. Flying altitude (x_1).
2. Number of bombers per mission (x_2).

Here both factors are controllable. At first sight, there seem to be some uncontrollable dominating factors in this situation, such as the weather and the type of defense used by the enemy. However, the weather can be controlled to a certain extent by selecting the time of attack. Also, enemy defense can be assumed to be constant for a certain length of time.

It is further assumed that the worth can be fairly accurately measured by photographic or other means, and that both worth and cost can be evaluated in common terms, e.g., man-hours.

The problem, now, is to find the flying altitude (x_1^o) and the number of bombers per mission (x_2^o) which will maximize gain in circumstances where the functional relationship $G(z) = f(x_1, x_2)$ is not known.

Technique Illustrated

For some time in the past, the bombing unit has been flying at an altitude of 10,000 ft. with 20 bombers per mission for a certain type and size of target. To start with, it is proposed to design an experiment and compute the gradient of steepest ascent in the neighborhood of this point (10,000 ft., 20 bombers) by fitting polynomial of the first degree:

$$G(z) = a_0x_0 + a_1x_1 + a_2x_2 \qquad (1)$$

where,

$x_0 = 1$, and a_0, a_1, and a_2 are constants to be determined.

This is to be interpreted as follows: a_0 gives the value of $G(z)$ at the experimental origin.

$$a_1 = \frac{\partial G(z)}{\partial x_1}, \quad \text{and} \quad a_2 = \frac{\partial G(z)}{\partial x_2}$$

indicate the proportional change which should be made simultaneously in levels x_1 and x_2, respectively, for steepest ascent in the neighborhood of the fitted polynomial.

It might be noted that this polynomial takes into account the first order effects only (hence a minimum of $2^2 = 4$ points will be required). This is considered quite satisfactory for the first experiment since there is no reason to believe that the system is operating in the neighborhood of an optimal response.

The origin 0 for the first experiment is taken at the point (12,500 ft., 30 bombers) and the factor levels for the experiment are:

Factor	Factor Level		Experimental Design Unit
	−1	+1	
x_1 Flying altitude in feet	10,000	15,000	2,500
x_2 Number of bombers per mission	20	40	10

The four experimental points ($i = 1, \cdots, 4$) and their observed responses $G_i(z)$ are given in Table I.

We now compute constants a_j's by using the formula:

$$a_j = \frac{\sum_{i=1}^{4} x_{ij}G_i(z)}{\sum_{i=1}^{4} x_{ij}^2} \qquad (\text{for } j = 0, 1, 2).$$

$$\text{Hence, } a_0 = \frac{\sum_{i=1}^{4} x_{i0}G_i(z)}{\sum_{i=1}^{4} x_{i0}^2} = \frac{802}{4} = +200.5$$

$$a_1 = \frac{\sum_{i=1}^{4} x_{i1}G_i(z)}{\sum_{i=1}^{4} x_{i1}^2} = \frac{84}{4} = +21$$

$$a_2 = \frac{\sum_{i=1}^{4} x_{i2}G_i(z)}{\sum_{i=1}^{4} x_{i2}^2} = \frac{142}{4} = +35.5$$

Substituting these constants in equation (1), we get:

$$G(z) = 200.5 + 21x_1 + 35.5x_2 \qquad (2)$$

This is the equation to a plane and indicates that at the origin (12,500 ft., 30 bombers), $G(z) = 200.5$ units. Furthermore, it indicates that for steepest ascent in the neighborhood of the origin, levels of x_1 and x_2 should be changed in the proportion of +21 and +35.5 experimental units respectively.

TABLE I

First Experiment

i	x_{i0}	x_{i1}	x_{i2}	$G_i(z)$	$x_{i0}G_i(z)$	$x_{i1}G_i(z)$	$x_{i2}G_i(z)$
1	1	+1	+1	+266	+266	+266	+266
2	1	−1	+1	+206	+206	−206	+206
3	1	−1	−1	+153	+153	−153	−153
4	1	+1	−1	+177	+177	+177	−177
Sum					+802	+84	+142

The design unit for bombers is 10 and that for altitude is 2,500 ft. If we decide to advance in steps of 5 bombers, this should be matched by an increase in flying altitude of:

$$\frac{1}{2} \times \frac{21}{35.5} \times 2500 = 740 \text{ feet.}$$

We can now advance from the origin in steps of 5 bombers and 740 feet, observe the gain $G(z)$ and compare it with the theoretical gain based on the supposition that our extrapolation using equation (2) is valid.

For the purpose of computing this theoretical gain, equation (2) can be simplified to:

$$G(z) = 200.5 + 21 \times \frac{740}{2500} U + 35.5 \times \frac{5}{10} U$$

$$= 200.5 + 23.97U \qquad (3)$$

where U is the number of steps from the origin and takes on positive integral values starting with zero at the origin.

This analysis has been made for $U = 1, \cdots, 12$ and recorded in Table II. It is seen that the extrapolated value of $G(z)$ differs materially from the observed value for the fifth and subsequent trials. This shows that the extrapolation has been carried too far and that higher order effects are probably becoming more important in this region. Furthermore, empirically observed $G(z)$'s for trials 11 and 12 seem to be approaching a stationary level (indicated by small increments) which might be a signal that the system is being operated in the neighborhood of a peak response.

At this stage, it is, therefore, desirable to design a second experiment and either take the second order effects into consideration by fitting a polynomial of second degree, or reduce the length of the steps for x_1 and x_2. The method of computation is the same as that illustrated for the first experiment; when the increment in $G(z)$ between two consecutive steps starts changing sign, it might be necessary to move back and forth to explore the region locally until the peak is determined.

TABLE II

First Series of Trials

	Factor Levels		$G(z)$	
	x_1 Feet	x_2 Bombers	Obtained by extrapolating the plane fitted at base level	Empirically observed value
Base Level	12,500	30		200.5 (average)
Unit of Design	2,500	10		
Estimated Slope (a_i) of Fitted Plane	+21	+35.5		
(Unit)$x(a_i)$	52,500	355		
	740	5		
Change in Level for Change of 5 Bombers per Mission				
Trial U = 1	13,240	35	224.5	220
2	13,980	40	248.4	260
3	14,720	45	272.4	270
4	15,460	50	296.4	280
5	16,200	55	320.4	285
6	16,940	60	344.3	290
7	17,680	65	368.3	298
8	18,420	70	392.3	304
9	19,160	75	416.2	308
10	19,900	80	440.2	316
11	20,640	85	464.2	318
12	21,380	90	488.1	320

In this case, since the underlying relationship on which the example is based happens to be known, it is ascertained that the optimal conditions are:

$$\text{Max. } G(z^o) = 329.8 \text{ units}$$

$$x_1^o = 21{,}000 \text{ ft.}$$

$$x_2^o = 120 \text{ bombers}$$

The reader can easily verify how close he can get to the optimal conditions by obtaining the functional relationship from (11) and making further computations.

Summary

Numerous important contributions to the methodology of sequential decision making have been made in recent years. One efficient experimental design technique for response surface exploration, which uses the principle of steepest ascent, has been suggested by G. E. P. Box. The technique is particularly useful when the underlying functional relationship between the dominant factors and the response of a system is not known.

Applications of the technique have been made in the chemical industry. The methodology involved in the technique seems to suggest that the technique can be effective in many other industrial, management sciences, and military decision making situations.

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Automation without a Heavy Investment in Equipment

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American industrial progress has always been based upon the economic concept of capitalism as expressed in the "innovationist" concept given us by the Schumpeter School. It is small wonder, therefore, that American management in general is constantly looking for new and different ways of improving business activities. During the last 100 years the term "mechanization" has given us a tremendous impetus and according to the statisticians has raised our productivity per man hour from 1850 to 1955 by some 600 percent, and latest predictions indicate that the next 25 years will see industrial progress such as the world has never known.

Underlying this tremendous potential expansion in our economy, the theoreticians have coined new phrases and new concepts. Among these words and terms we find "Operations Research," "Linear Programming," "Integrated Data Processing", and above all others "Automation." Most people seem completely mystified by these terms. Many business managers and top management executives who have come up through the ranks over the past 20 or 25 years seem worried lest the technician or engineer who is adept at using and talking about these new techniques may take over and eliminate the necessity for the present management class. Apparently the die seems to be cast, and, unless we can become conversant with these terms and techniques, all will be lost, and the present generation of business management will be forced to take the back seat in favor of those who can *talk* in the new language of the new concepts.

Is all this true? Are we perhaps not building a system of verbal "gobble-de-gook" that merely shrouds existing techniques, that most of us have been practicing for a long time, in a new maze of incomprehensible terms? As a practicing industrial engineer and management consultant for the best part of 20 years, I feel that I have been practicing these techniques in actuality without giving them a name. Every senior company officer who collects facts and figures, who lays out these facts and figures in a systematic fashion, who draws upon his own and others' past experience and knowledge, and using "considered judgment" comes up with a composite answer based upon these areas of knowledge, is a practitioner of Operations Research. Any elimination of duplication of effort practiced by a member of a company, whether it be in factory tooling or in clerical activity, is in essence the practicing of the idea of "Integrated Data Processing." Furthermore, practical automation has been the aim and objective of management personnel for many years.

Such ideas and concepts could not have been superimposed upon the industrial picture as quickly as they have been if there had not been a sound foundation and basis for their application. Let us look at them from the point of view of extensions of present practices and techniques, rather than something completely new and different which has come from revolutionary ideas and concepts never thought of before.

There is nothing magic nor panacea-like in the mere names of electronic systems and computors. No new development in office equipment should be considered without first acquiring knowledge of the company's own systems, procedures, clerical costs, report requirements, and other special problems; and this cannot be too strongly emphasized. The equipment itself is merely the means and the tool which is used to accomplish the end. It is not the end in itself. Management must be careful to segregate potential savings from Automation and the savings from the *preparation for its application*. Too often we find that the introduction of a new system or procedure itself is credited with effecting major savings and improvements, which in reality have resulted from the analyses necessary prior to actual installation. Furthermore, any new installation of automatic equipment can in many cases cause difficulties hitherto unseen, and may virtually wreck the existing company's structure unless the proper foundation is laid for its installation.

I am reminded of the situation a number of years ago when the word "mechanization" was sweeping the country like wild fire, and many companies were reaching out in an attempt to purchase more machines that would replace manpower. Installations were being made in such a hurried fashion that the proper foundation would not be constructed for their application. In this particular case, a new machine which would replace 15 people was hurriedly ordered and upon its delivery was placed into the production line and management sat back awaiting the results. Because of the heavy weight and vibration of this

machine, after several weeks of operation the floor gave way, and the machine went from the third floor to the basement right through the building. I know of a large company in the Philadelphia area that purchased new profiling lathes which were designed for one operator to run four machines. When the new machines arrived and were placed on the floor, a serious problem developed between the union and the management. The union struck on the basis that one man had always operated one lathe, and therefore they would not permit their men to operate four lathes. The end result of this situation was that we now have one man operating two lathes which was a compromise from the first position. The company invested many thousands of dollars in expensive equipment which is now being utilized approximately 50 percent effective because instead of one man operating four machines, they have one man operating two machines.

In the early days of tabulating punch-card equipment, a large electrical manufacturing company was presented with a suggestion by an employee, through the suggestion system. This suggestion was to the effect that punch-card equipment be installed for certain phases of accounting and payroll activity. The estimated savings were calculated, the equipment was installed, and the employee was given a financial reward through the suggestion system. All this was done in the hurry of reaching out for the new concept that was relatively untried, and proper investigation was not made of all the potential problems in the application. Approximately two years later a suggestion was put in through the suggestion system, and the suggestor was given a financial reward on the basis of the savings for his suggestion. The suggestion consisted of eliminating the punch-card system because of its high cost. The suggestor was the same individual who had put in the original suggestion to install the equipment two years previously.

Recent studies brought to my attention indicate that up to 80 percent—in some cases more—of the total savings attributed to Automation, have really been brought about through preparatory work in setting up for the automation, rather than in the application of the machines and systems themselves. These savings will accrue whether the new equipment is obtained or not. In fact, we may draw the conclusion here that when top management has merely expressed a wish to investigate the potentialities of automation, the necessary investigation starts chains of reactions that when properly handled bring about major savings and cost reductions. Automation, therefore, is similar to the icing on a cake. If it is a good cake, properly baked and well raised, the icing will be successful.

A recent survey indicated that out of twelve companies that instituted automation for the purpose of reducing numbers of employees, only two achieved the expected results. The other ten companies wound up in the final analysis with more employees than they had previous to the installation of automation. These statements that I have made probably do not seem to tie in with much of the publicity that has been given recently to systems of integrated data processing and automation. Many companies have gone on record as stating that tremendous savings have accrued to them as a result of the application of electronic systems. Much of the present literature would indicate that the installation of the physical machines themselves and the electronic systems themselves have been responsible for these savings. Yet, let us look at it from the point of view of a more complete breakdown of the facts. In many cases these savings have been lumped. No effort has been made to segregate the savings from the control and standardization of procedures, records, and personnel, from the savings represented by the application of specific kinds of equipment for automation.

This kind of thinking is similar to that which pervaded the management sphere some years ago when the popular rush was to wage incentives. Many savings were attributed to actual incentive plans, when in reality the increase in pace achieved by the operators in an attempt to earn more money was a small portion of the savings, the largest part of which came in the methods and the standardization of procedures and production flow prior to the actual installation of the wage incentive system. We cannot merely lump our costs and take our entire cost picture prior to the installation of automation, and our cost after the installation of automation, and say in effect that the net savings is attributable to the application of the expensive machinery itself.

Not long ago one of the leading scientists in the development of electronics equipment said, "The equipment is available to process any data business wants processed. The big problem is to analyze the requirements of business and set up a system which can be followed effectively." He warned against getting electronic equipment capable of handling existing systems and all possible variations; this would be far too expensive. He recommended that a proper system analysis be made and paperwork requirements be properly established, so that only the specific electronic equipment required for the job would be necessary.

Let us now ask the question, "How can we initiate our plans and objectives to obtain the greatest potential savings?" To answer that question we must go all the way back to the beginnings of the scientific management movement. Frederick Winslow Taylor, who has been referred to many times as the "father of scientific management", stated in testimony before the Congress of the United States in 1914 as follows:

> Scientific Management is not an efficiency device, not a device of any kind for securing efficiency; nor is it any bunch or group of efficiency devices or equipment. It is not a new system of figuring costs; it is not a scheme of paying men; it is not a piece work system; it is not a bonus system; it is not a premium system; it is no scheme for paying men; it is not holding a stopwatch on a man and writing things down about him; it is not timestudy; it is not motion study or the analysis of movement of men; it is not the unloading of a ton or two of blanks on a set of men and saying 'here's your system, go use it'; it is not divided foremanship or

functional foremanship; it is not any of the devices that the average man calls to mind when scientific management is spoken of. . . . I believe in them; but what I am emphasizing is that these devices in whole, or in part, are not scientific management; they are useful adjuncts to scientific management. It involves a complete mental revolution on the part of men . . . and it involves the equally complete mental revolution on the part of those on management's side. . . .

It is well to remember that Frederick Winslow Taylor's caution was well taken because to this day we can generally accept the statement by Dr. Harlow S. Person at the 8th International Management Conference in 1948 that:

Generally, throughout all areas of management, including industry, there is absence of an overall perspective and a comprehension of scientific management as an integrated whole. . . . The interest has been focused on mechanisms and devices. . . . Specialization in mechanisms and phases have become dominant. . . .

Management traditionally has been by specialists who have "built empires" and have pictured their own functions as *most* important. We must coordinate all phases of top management, and develop the "team concept." In looking at automation we cannot continue our traditional managerial thinking of compartmentalizing the various phases of management. One significant development that has been noted in this field is the growing need in the application of automation to be able to cross the old departmental lines. While integrated data processing has been thought of essentially as an office phenomenon, its reach can extend well outside the office, and must, for successful application, reach into every department and division of the company.

For example, in respect to merchandising record keeping, pre-punched tags can be attached to garments or other goods. After a sale the tags can be introduced into converters which will transfer relevant information such as price, size, department, etc., onto a standard punch card or onto a punched paper tape. Obviously in such a case the retail sales organization must be coordinated with the accounting organization if the system is to be effective. Similarly, the various kinds of point of sale equipment for recording original accounting information on tape or card form at the time of the sale must be set up to produce records which can be used in other parts of the organization. Still another possible application is the use of employee identification cards with pre-punched information. Used in place of time cards they are used to originate certain payroll accounting records in the factory itself. It is clear, therefore, that the ultimate uses of integrated data processing will penetrate into all activities of a company including its production facilities, its warehouses, its sales department, and in short into every function which may be asked to keep records of any sort.

We must develop an "operations research concept" in our very management thinking. No longer can a decision be made in one area of management without thinking of the repercussions that will occur in other phases of managerial activity as a result of that particular decision. Let us think of coordinating at least seven basic areas of management activity as a sound foundation for automation.

1. The coordination of *manpower*. The personnel department and the decisions with regard to job analysis and job evaluation must develop a more clear cut understanding of exactly what type of individual is required for each job, and it is necessary to establish the sound basis of clerical cost control and work measurement. In the very study of standardization of manpower requirements we very often find savings, not through the application of mechanical equipment, but through the supplying of the right kind of a worker in the right job, working under the correct conditions, and with the best possible equipment. The personnel department must therefore coordinate its activities with all the other phases of management.

2. Materials control and standardization. We must standardize such specifications for the kind and type of material that we need in all activities in our business. No longer can we depend upon individual intuition in determining whether or not we should accept sub-standard material, nor should we accept it in small lots rather than in the proper number of pieces that are required to feed into our concept of automation. Materials must be standardized even down to the kind and type of carbon paper, bond paper and cards that we will use, as well as standardized materials for our production lines. We cannot hope to obtain the best utilization of manpower unless we give that manpower the best and most standardized materials to work with. Many companies can make substantial savings in materials control, inventory and standardization while concurrently considering steps to automation.

3. Machine purchase, replacement and utilization. Are we using to its fullest advantage every piece of machinery that we have at the present moment? Are we depreciating it on the basis of obsolescence, or on the basis of the time honored accounting long term depreciation? Are we spending too much money on wasted material and wasted manpower to use machinery that has already outlived its useful life in terms of the obsolescence factor? I am reminded of the typical statement of the accountant which goes something like this: "We have long since fully depreciated this machine on a yearly basis and I carry it on the books at the present moment at scrap value. Therefore, it logically follows that any production we get from this particular machine is a pure gift and therefore we should be making money on it." However, looking at it from a non-accounting view, we may find that it is wasteful of materials which are getting more expensive every day, and of manpower, costs of which have skyrocketed. While taking a time study on a machine operator, I noticed that the operator was leaning on his machine. I marked on my observation sheet, "Operator idle — leaning on machine." A few days later the foreman called me up and said, "Schoeller, in your study you should have given that man credit for performing an operation." My answer was, "He was doing nothing but leaning on the

machine." The foreman said, "For your information, *he had to*, that machine is so old and has bearings that are so sloppy that he was leaning against the shaft of the machine so that it would maintain the proper tension for cutting." Here we have a situation in which the company was paying twice as much for the operator as it should have on a better machine, and the labor cost to operate an old fully depreciated machine was far more than the investment cost of a new machine.

4. Monetary and fiscal policies. We must coordinate with all the other phases of management, our fiscal policies with relation to purchase of new machines, changes in material specifications and manpower controls. We must determine the advisability of spending money for automatic equipment, or whether or not we may do the same job using manpower dependent upon our particular type of business. No longer can we look merely at financial returns per dollar invested, but we have to look ahead into the future to see what an investment today may bring back in terms of added returns or potential difficulties in the future.

5. Methods and procedures analysis. Installation of new methods and machines for automation in one department may cause us difficulties in other departments. We must be careful to coordinate the activities of the methods department so that no longer can a method be discussed as it applies at the point of use, but in terms of how it applies in terms of the entire organization. Very often our initial investigation into the potentialities of new methods may serve us far more in laying the proper groundwork for automation and in immediate savings than if we attempted to move directly into automation.

6. Market coordination and control. The coordination of our sales policies, types of products sold, services advanced to customers, types and kinds of invoices sent out, discount policies with respect to our customers, all must be dealt with in the "new look" if we are attempting to lay a foundation for automation. Very often the redesign of a product or the redesign of our sales system may bring about tremendous savings in the coordination of the managerial team prior to any experiment into automation.

7. Managerial coordination and participation. By development of task analyses for our management group itself for the proper assignment of responsibilities and distribution of activities, and through the participation of our management team in decisions affecting the overall structure, we can very often institute savings that will be extremely well accepted and that will lay a proper foundation for later automation. We can see, therefore, that the 80 percent savings we previously discussed are entirely possible, through the very preparation and investigation of the possibilities and potentialities of automation.

The question, of course, is *where* do we start and *when* do we start? The answer is that we can start immediately. Under development of the best and smoothest flowing concepts of these coordinated activities we can trace the potential development of possible automation, which can be expressed as flowing from, first of all, a sound work simplification and methods program, which would include training of all levels of management from the top down to the supervisory level, and investigation into the possibilities of changing and standardizing the methods on all jobs as quickly as possible.

Our next step would be to see where we could institute such things as simplified automation which might be in terms of single writing systems which would in certain areas enable us to collect information of a common language variety in preparation for the final completely automatic system.

Thirdly, we could begin a standardization program to standardize all job analyses and evaluation of materials, machine processes, monetary and fiscal policies, systems and procedures policy manuals, sales manuals and standard operational procedures for managerial decisions to develop a management concept on the exception principle. After we have accomplished these goals, then we can logically move towards mechanization. First of all, on a simplified basis and in certain areas where it lends itself to the best possible installation, specifically in those areas where the greatest amount of detail or routine work is performed.

Finally, after having laid this groundwork, which in some companies may take as long as two to five years, we are then ready for an integrated data processing and automation system.

In every one of these steps potential savings are available. The steps should be looked at in chronological order and a move to the next step should not be made until the potential savings are recognized and realized in that particular area. This is similar to a person walking up a set of steps. If we attempt to leapfrog several steps, there is a definite chance that we may trip and fall down the entire flight of stairs; but if we progress from step to step, carefully placing our foot solidly on each step before proceeding to the next one, we have then realized the full savings from each step.

Concurrent with such a program, of course, there must be a coordination program which would be looking at all times toward the end result, in which we would be guiding each of these steps towards the eventual automation of the entire picture. It would therefore be a sound step for management to organize a function which would coordinate all of these activities and would lay long range plans for the integration of the entire system to a whole, when and if the company is ready for it.

It is foolish to go into the idea of automation and then find out later that the whole procedure was really unnecessary and could have been eliminated in a work simplification program. We can properly plan for automation by following this series of logical steps. These steps are really nothing new. They are steps that any management should investigate, irrespective of whether or not it is contemplating automation. These steps are in effect a working plan of sound modern control concepts that become a

sound foundation for real cost and managerial control.

Looking at the problem from an overall plan point of view, let us consider immediate steps that can be taken by any management in preparation for automation, or as we might say in preparation for any sound control program. We may set up a plan as follows:

1. Information flow analysis. No business can operate without knowing how its information flows down through the business, and how the reports of progress flow back to management. Our information must be current. It must give us what we want when we want it. Have you ever upon returning home from a trip of two or three weeks started to read the old newspapers that you forgot to stop and that have in the meantime been accumulating on the doorstep? They really present little that interests us. To put it another way—if you are planning a picnic with the kids tomorrow, you don't look at a three-week-old newspaper to determine whether it is going to rain. What you are looking for is tomorrow's newspaper tonight with the up-to-date weather forecast. We all know that we can't have this ideal situation of knowing tomorrow's racing results today, but the closer we can get to the so-called crystal ball, the better. The first thing we must know is how is our information flowing at present? Some people would call this the act of communication. But here we see something different from communications in itself. The so-called art of communicating is one thing, but the flow of information as such is really a series of communications coupled with written and verbal reports and orders. We can start immediately on an information flow analysis program. We can begin to collect every report, every chart, every activity, that is being done. Bring them into a central location—put them on a chart—determine just exactly how much information flows around our particular company. Most managements would be amazed to know how much time of their executives and their production people is spent merely in asking and disseminating information. Present systems of information flow in many companies do not lend themselves to automation. It therefore behooves us to immediately begin a program of information flow analysis to standardize and control this flow concept and obtain the savings available there.

2. Reporting systems and report studies. One of the advantages of beginning with information flow analysis is that it begins to collect in one place all of the reports, charts, graphs, and cost analyses. A study of one of the divisions of our largest companies showed that management felt that they had some 52 different reports in this company. Upon investigation and carefully digging through the files, and interviewing everyone to whom the reports went, it was found that more than 250 actual reports existed. Two hundred and fifty reports—when management thought it had 52. This is probably true of most managements who have not made a complete study of their reporting systems and of the records and reports that presently circulate throughout the plant. Reduction of duplicate reports, elimination of unnecessary reports, all can be started immediately, rather than waiting for a completely automatic system. In addition to which, there is the danger of instituting an expensive data processing system for a report that really wasn't necessary. Tremendous savings are available in this particular area alone.

3. Work distribution analysis. Here we mean the analysis of work distribution from the top management down to the lowest levels of management. How many top executives are doing routine clerical work? How many people are attempting to do work that has been delegated to them of a higher responsibility than they have the calibre to complete? By properly distributing the type of work and character and the number of different kinds of work that a person does, we can institute marked savings immediately.

4. Forms design and control. Many managements today are embarking upon a system of forms control. Many managements are not. Here is an area in which there are literally millions of dollars to be saved. A large company starting out on such a program merely made a physical collection of every form that was being used in the company. In all, more than 3000 forms were collected. Many forms were duplicates, many forms were "alibi" forms, many forms were unnecessary, had been started at one particular time and had never been stopped, even though the reason for their starting had long since disappeared. As a result this particular company cut down its 3000 forms to less than 1000 in the space of two years.

5. Job description, analysis and simplification. It seems to me that in the field of automation we are becoming accurate to such a fine degree that apparently we have very badly missed the boat when it comes to a proper program of job description and analysis. Our whole technique of job analysis and evaluation and employee selection and testing in most businesses needs a complete overhaul. Many savings in labor turnover and dissatisfaction of employees and employee morale can be made if we put square pegs in square holes, instead of our present personnel policies which produce many thousands of dissatisfied workers. Job analysis itself can institute many savings in this reduction of turnover, especially where we find in many businesses today that the hiring of a new employee may cause as many as 200 different forms being initiated and filed. So turnover costs money. Proper job description can reduce turnover. Simplification of jobs comes as a part of job analysis. We can institute here programs of basic motion economy and work simplification, safety studies, all of which lay the proper foundation and groundwork for further investigation in electronics and automation.

6. Work measurement. Work measurement in terms of manual activities in industrial situations has been in effect for many, many years. Clerical work measurement is in its relative infancy. However, if we are going to lay any foundation whatsoever for automation, we must standardize and measure the time required to perform any task. If we do not, then we are building a structure on

top of an extreme variable which will not give us the results that we want in the long run. Clerical work measurement programs have brought about savings high in the thousands of dollars, in some companies more than a million dollars in return. It behooves us, therefore, to start immediately a program of work measurement, if we have not already done so.

7. Records and filing procedures. Once we have standardized our reports, our reporting system, our forms, and our job descriptions and analysis, we can then begin a program of filing procedures and recording devices. We can standardize our records so that they will fit in with common language machines and micro-filming procedures as time goes by. Here the coordination of the individual or the management in terms of looking forward to automation can give us much of the foundation that we are laying for a sound system. In the very studying of our records and our filing procedures tremendous savings are available, especially since floor space costs have recently skyrocketed.

8. Layout and space utilization. If we are looking forward to automation where are we going to put the machines? Where are we going to centralize our data processing? How is our information going to flow? All of the previous steps funnel into the program of layout and space utilization.

We can therefore conclude that automation is really an extension of scientific management as envisioned by Frederick Winslow Taylor. The mental revolution of which he spoke is really one of applying principles and not machines and techniques on a basis of overall managerial cooperation, rather than on a basis of individual projects aimed at solving problems of the moment. The problem is one of building towards automation without a heavy investment in equipment until such time as we have the sound and solid foundation and we have achieved all of the potential cost savings possible before the installation of the expensive and intricate machinery which can become obsolete in a very short period of time.

The plan and program is difficult only when we think of it from the point of view of the mental revolution required. If company officials are not yet doing anything about it, it must be that they haven't realized the possibilities. We must develop an alertness among top management of the actual cost of operations as they exist at the present moment. A dollar saved in present cost is just as big on the balance sheet as a dollar saved in mechanical investment. In fact, many of the steps referred to here really require no expensive investment in equipment. What they do require is a set of sound policies to immediately embark upon investigation of potential savings that are immediate and lay the foundation for further mechanization. Both phases of the program can progress side by side at almost an equal speed. The problem is really one of how to immediately implement the program.

If we are to assume that top management is properly aware of the possibilities for savings in the field, then what is the next step? The real step of importance is the selection of a qualified person to coordinate, administer and lead the program. This person can be called Director, Manager, Coordinator or whatever you like. His department may be known as Methods, Methods and Training, Systems and Procedures, Controls Coordination, Administrative Controls or by any other designation. The position should be in a staff relation to top management. The responsibility should include guiding those involved in determining what administrative and operating controls are necessary; stimulating and guiding others in development of adequate systems to provide the information necessary for all controls and other purposes; the training of people in necessary techniques so that they can work together and develop a more effective system of methods; making available information regarding equipment, materials, etc., and new developments; providing specialized techniques or technicians when desirable; and the administration of the entire activity.

The next step is to have top management appoint a coordinating committee of top operating people representing each operating function as mentioned above with our leader as chairman. The objective of this committee should be the coordination of all systems, controls, improvements and problem solving activities in proper relation to each other towards the broad objectives of the company. They must appreciate the importance of generating interest and enthusiasm from top to bottom and the value of "participation with know how" in accomplishing this. To this end they should be the first to participate in the training program. The committee will help to determine broad policies and the necessary end results of the systems. They will guide and be sure that responsibilities are properly delegated and that people meet those responsibilities.

Whether in the final analysis people, machines operated by people, machines operated by a common medium guided by people, or electronic equipment guided by people to do the work, depends on the cost of the end result and the ultimate long term benefits to the company. Linear programming and operations research, as well as automation with feedback control, help solve problems and should be no mystery to this committee. High speed computors make possible the rapid processing of analysis of information to evaluate various approaches to a given problem and provide a more sound basis for the exercise of good judgment and remove much guess work. But again the values derived must justify the cost, and the system is the foundation. Even more important are the people who do the work. The more they are involved in the improvement program, the more effective will be the results. The worker; the coordinating committee; or the top operating executives representing each line or operating department in establishing broad policy, in guiding the integration of systems, equipment and functions, and stimulating interest and enthusiasm, by involving people at all levels and developing better methods—can be of tremendous value in initiating and maintaining a successful program on a long term basis.

Multiple Factor Incentives for Process Industries

By James F. Emerson

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As process industries have grown more complex, improvements in instruments and in remote control devices have made it possible for the operator to extend his area of control, and at the same time have limited his area of activity. Where he formerly emptied bags of material into a mix tank, he now simply pushes a button to start or stop a conveyor; where the old method of control was personal observation, he now checks temperature and pressure and vacuum recorders.

This confining of the operator to the immediate environs of the control panel has posed quite a problem concerning the successful application of manual work incentives. While the work of reading gages and operating controls lends itself to conventional time study, sufficient work is generally not available in the immediate area to permit above-normal manual performance with the resulting bonus earnings.

One method of bringing a successful incentive application to this type of job is to tie (1) manual work with (2) operating results. When consideration is given to the fact that in many instances operating results far outweigh manual effort in importance, dollarwise, the addition of work *results* to work *input* seems a logical step.

The "how" of combining these two measurements to arrive at a bonus figure is simplified materially by looking at a graphic presentation of the normal one-for-one incentive plan, Figure 1.

With the manual efficiency (standard hours produced, divided by hours spent on standard work) of the process operator at or possibly slightly below 100%, it is apparent that any alterations of the normal incentive application must involve the area "X", above the 100% of base wage earned line.

As shown in Figure 2, one way of tying in machine output or quality results is to use the "X" area for the addition of a third variable (in addition to "Per Cent Work Output" and "Per Cent of Base Wage Earned"). This is termed "Operation Efficiency", and, as illustrated in Figure 3, is drawn in with certain arbitrary limits. In this example, the operation efficiency additive is made to disappear at 125% manual efficiency, minimum operation efficiency for which added bonus is paid is 70%, and no

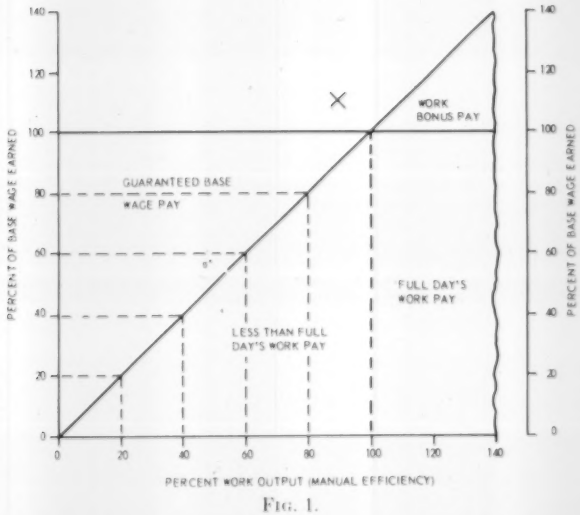
PERCENT OF BASE WAGE EARNED
PERCENT WORK OUTPUT (MANUAL EFFICIENCY)
WORK BONUS PAY
GUARANTEED BASE WAGE PAY
FULL DAY'S WORK PAY
LESS THAN FULL DAY'S WORK PAY

FIG. 1.

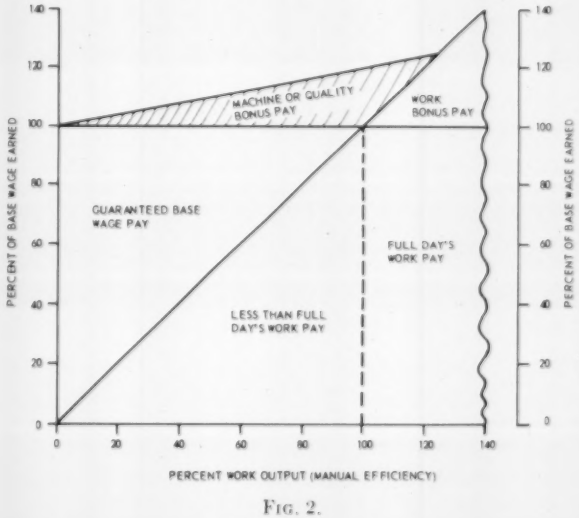
PERCENT OF BASE WAGE EARNED
PERCENT WORK OUTPUT (MANUAL EFFICIENCY)
MACHINE OR QUALITY BONUS PAY
WORK BONUS PAY
GUARANTEED BASE WAGE PAY
FULL DAY'S WORK PAY
LESS THAN FULL DAY'S WORK PAY

FIG. 2.

operation efficiency bonus is added when the manual efficiency is below 70%.

These limits were selected for the following reasons:

1. As manual output increases above 100%, the operator has less and less time to devote to process results. At some point, 125% manual efficiency in the example at hand, it must be assumed that he is giving his full attention to muscular coordination, and has no time to spend on machine or quality results.

2. The 70% minimum operation efficiency was selected because when results drop below this figure it seems reasonable to say this level of operation is unacceptable.

3. When the manual efficiency of the operator is below 70%, he has so much time available to devote to process operation that good results should be expected without any incentive beyond base pay.

Obviously conditions will vary between industries and companies, and the limits of the operation efficiency portion of the chart must be altered accordingly.

For determining bonus with a plan of this sort, it is necessary to have only manual efficiency and operation efficiency. In the sample calculation shown in Chart 3, 93% manual efficiency and an operation efficiency of 95% will pay 15.5% bonus. This percentage should in turn be applied to the number of hours on standard work.

"Operation Efficiency" as used here is a generic term, and is meant to apply equally well to packaging equipment throughout, process yields, chemical analyses, material spoilage, and so on. In each case it is necessary to translate results to an efficiency basis, as follows:

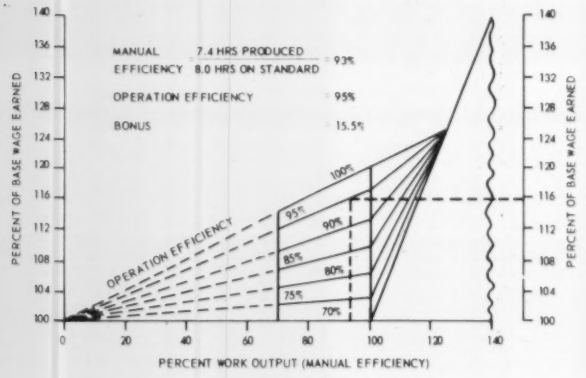

FIG. 3.

1. Packaging equipment throughout efficiency = actual cartons packed, divided by the machine speed in cartons per day.

2. Process yield efficiency = $\frac{(\text{Actual} - \text{Normal})}{\text{max.} - \text{Normal}} 3 + 70$, where "Actual" is the actual yield in per cent, "Normal" is the yield above which bonus will be paid, and "Maximum" is the maximum theoretical yield attainable.

3. Chemical analysis results are converted to an efficiency basis by selecting certain narrow desirable limits as 100%, and arbitrarily selecting specific points above and below this range as 70% operation efficiency, 75%, 80%, etc. Thus, if pH is a critical operating control, 10.0 ± .5 might be 100% operation efficiency, while 70% would be 8.0 pH or 12.0 pH with intermediate points being 75%, 80%, etc.

4. Material spoilage is translated into efficiency terms by determining from past experience what the bogey, or expected loss should be. This, then, is considered as 70% operation efficiency, with zero loss being 100% operation efficiency. The formula for conversion is: Op. E. = $\frac{(B - A)}{B} 3 + 70$, where "*B*" is the bogey figure and "*A*" is actual.

For any given operating job, several items may be considered important enough to be included in the operation efficiency figure. This is done by assigning a specific weight to each item. Generally, not more than four items should be used, as the interest of the operator may tend to lag if his responsibilities are diluted by being too wide-spread.

In the operation of a plan of this sort, it is necessary to set up certain "ground rules". Two of the most important ones are:

1. The manual portion of the incentive standard should contain only work necessary at 100% operation efficiency. The operation efficiency portion of the standard will pay the operator, through improved results, for any manual work he does over and above this.

2. No exceptions should be made in the calculation of operation efficiency, no matter how good the "reason" for not getting good efficiencies. The pay is for measurable results.

With further development ahead for process type industries, and "Automation" in all types of businesses becoming a by-word, paying for measurable results, but with due recognition of the manpower required to get those results, appears to be a logical step in the application of incentives.

Proceedings, Seventh Annual AIIE Conference and Convention

May 17–19, 1956—Washington, D.C.

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American Institute of Industrial Engineers, Inc.
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A Dissertation upon the Superfluity of Gobbledygook

By Robert Hays

Assistant Professor, Southern Technical Institute

The title of this article would probably frighten most readers. "Here," thinks the average reader, "is another one of those articles just loaded with long, 'five-dollar' words. I wonder why a magazine would print such stuff."

This title should scare a reader. An expert on grammar would say that the title contains three nouns, two short words ("a" and "the"), and two prepositions ("upon" and "of"). At least four of the words—the prepositions and "a" and "the"—are short, familiar words. But those three nouns, "dissertation," "superfluity," and "gobbledygook," would make almost any reader want to turn the page to another article. These nouns are "gobbledygook". And to a reader, gobbledygook is poison, unless he has unlimited patience or unless he knows he ought to read the article or story to find out what it contains.

"Gobbledygook" means unnecessary literary stuffiness, the use of needlessly difficult words to carry little bits of meaning. Gobbledygooking, substituting a "five-dollar word" in place of plain English, has appeared almost everywhere, especially in industrial and scientific publications. Anyone who writes letters, reports, or research papers should understand why gobbledygook, sometimes called "bafflegab", so often appears. He should also know how gobbledygook discourages a reader, and how to avoid gobbledygook.

Almost everyone would agree that serious writings—an industrial report, the record of a research project, a news story, a business letter—have in common just one fundamental purpose: to tell a reader about a subject in which he should be interested. Conveying information is the basic purpose of non-fictional writing. From this basic purpose develops a second fact: non-fictional writing is best when it most efficiently conveys the information to the reader. Therefore, writing unnecessarily difficult words, building a language barrier between the writer and the reader, using gobbledygook—all mean poor writing.

Fortunately, many chances for gobbledygook have been missed. A coin might have carried the following inscription, devised by some bafflegabber in the U. S. Mint: "It needs be that in the Creator should be our residual confidence for His Omniscience and Foreordination." But this would sound strange. The average reader can better understand the Mint's motto, "In God we trust." Or children might have been forced to memorize the following quotation:

"Approximately .87 century in the past, the predecessors of this convened assemblage engendered on this continent a newly established autonomous enterprise, characterized by its aura of disenthrallment and adhibiting the postulate that all representatives of the genus homo sapiens are fabricated in a state of enfranchisement."

But, again, Lincoln's Gettysburg address in gobbledygook would have been difficult to understand, more difficult to memorize.

However, readers do have to struggle with gobbledygook, such as this quotation from a book intended for freshmen and sophomores in college: "Perception refers to the acquisition of specific knowledge about objects or events directly stimulating the senses at any particular moment. Perceptions or immediate presentations involve cognition (knowledge)."[1]

Obviously, these examples of gobbledygook fail to do what good non-fictional writing should do: efficiently tell the reader or hearer what the writer or speaker wants to write or say.

Many a reader might well ask, "Why do writers use gobbledygook? Is plain English not good enough for almost any factual writing?" A little investigation will reveal the answers to these questions. The first reason for using difficult words is this: some difficult words really are necessary for efficient writing and speaking. In fact, three types of difficult words are absolutely essential, especially in scientific and industrial writing: (1) the names of technical, industrial, and scientific equipment, (2) the names of many technical and industrial processes and operations; and (3) words with precise meanings for which there are no one or two-syllable equivalents.

Technical names include such words as "thyratron", "oscilloscope", and "manometer". These are the names of pieces of equipment, just as the word "screwdriver" is the name of a type of hand tool. Calling an oscilloscope a "gadget" would be inaccurate and misleading to someone familiar with oscilloscopes; although using the term "gadget" to name an oscilloscope would not be inaccurate in writing for an amateur, the word "gadget" would not tell him anything.

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1. Rudolph Pintner, *et. al.*, *Educational Psychology* (College Outline Series) New York: Barnes & Noble, Inc., 1951 (Fifth Edition). Page 52.

Difficult words also serve as the names of technical and industrial processes, such as "derivation," "interpolation," and "automation." And big words also help show differences in meaning if a common word has too many possible interpretations. For instance, the simple word "average" seems clear to a person not acquainted with statistics. He interprets statistics as purely mathematical averages. If three men, Jones, Smith, and Black, own automobiles, and if Jones has four automobiles, and Smith and Black one each, the reader not familiar with statistics would say that the average man in this group has two automobiles. Such an interpretation would not give the true picture of automobile ownership. A statistician might use the terms "mean," "mode," or "median" to show the automobile ownership, with each term conveying a different picture. The term "average" would simply not be accurate enough for statistical use.

Some difficult words, it thus appears, are essential. But using gobbledygook is a habit developed for another reason. All writers have become accustomed to the crossword puzzles which encourage a walking-dictionary approach to the language. These puzzles, often rewarding a person who solves them, suggest a high virtue in knowing a rare or obsolete word which means the same as a common word. The vocabulary quizzes in popular magazines also encourage a reader to believe that spouting words of five syllables or knowing the precise difference between flammable and inflammable[2] offers the reader a four-lane highway to wealth and health. In short, puzzles and quizzes imply that using large words, whenever and wherever possible, means being very, very intelligent.

Frankly, this implication does have some basis. General intelligence (as measured by the I. Q.) seems to correspond rather well to verbal intelligence, the ability to use words, to define words, and to understand words. But general intelligence would probably be even more closely related to the ability to use difficult words, *when difficult words are necessary.*

For the question, "When is gobbledygook really not gobbledygook?" is actually a question of "Is this difficult word really necessary; or is there a simpler word for this idea?" And the best advice for writers in the workaday world of business and industry, as well as for scientists and scholars would be this: Avoid verbal snobbishness! After all, an elementary principle of engineering is this: simplicity is the essence of good design. To ensure simplicity a writer in business or industry should ask himself three questions before he submits a report, mails a letter, or publishes a research paper:

"Is there a simpler word to carry my meaning?"
"Does this difficult word really carry my meaning?"
"Will the reader understand this difficult word?"

The scoffer who insists that he will not write down to his readers and that he will not insult their intelligence and his own by using simple words should realize the true purpose of non-fictional writing. Of what use is a literary side-show which tells the reader, "This writer has indeed a very large vocabulary (or a good dictionary)," but which does not tell the reader what the writer had to say? Communicating accurately does not mean condescending to the reader; it does mean informing the reader. The greatest writings in the language are so often the most simple. For instance, the Sermon on the Mount contains only one word ("righteousness") which could not be typed on the lengthwise space of a postage stamp with a small-type office typewriter.

Almost any literate adult can easily read the writings of a master craftsman like Winston Churchill. Why then should a representative of a governmental agency say (as one did), "We now have a quantitative framework with marginal qualitative allocations to formalize the procedure for further refining and implementing of our objectives."[3] The last few phrases, from "to formalize" to the end mean approximately this: "We want to find a system to get our job done even better." The rest of his speech could probably be reduced to plain English.

Reading gobbledygook is like eating that spun candy sold at the circus or the fair—much air, much space, but little solid matter. And spinning gobbledygook is no accomplishment, really. For instance, the surveyor, about to write in a land description the phrase "along the east bank of said creek" could substitute the dictionary for the transit and give birth to something like this: "in proximity to or adjacent to easterly limitation of aforementioned tributary." But the test would be, as in all questions of gobbledygook versus plain English, which would the reader understand better?

2. There is a difference.

3. Quoted in *Time*, March 24, 1952.

Institute Interests (cont.)

TOLEDO CHAPTER

The January meeting featured Mr. Bruno Moski, Director of Industrial Engineering for the Materials Handling Division of the Yale and Towne Manufacturing Company, Philadelphia, who spoke on "How to Measure Fork Truck Performance".

The speaker at the February meeting was Mr. Robert Beaman, from Delco Products Division of General Motors Corporation, Dayton. He has been with Delco for ten years; first in the capacity of a time study man and for the past two years as the Supervisor of Time Study. He was very well qualified to speak on the subject, "The Practical Application of Work Sampling Techniques."

The mysteries of M.T.M. and its possible applications were clarified at the March meeting. Mr. John P. Rives, Consultant for Methods Engineering Council of Pittsburgh, was the speaker. He spoke on "The Practical Applications of M.T.M." and not only covered some of the results that can be expected but gave examples of a few applications to specific operations.

Some of the future meetings of the Toledo Chapter will cover such topics as automation, plant visitation to the Whirlpool Seeger Corporation in Clyde, Ohio, and a preview into a new incentive installation.

INSTITUTE INTERESTS

BATON ROUGE CHAPTER

In March, the Baton Rouge, Louisiana Chapter held a joint meeting with the Louisiana Engineering Society.

The guest speaker was Professor Charles A. Reynard, and his topic was "Negotiations and Arbitration of Grievances in Collective Bargaining". He presented a very fine outline of the basic philosophy behind arbitration and the methods used in achieving acceptable results.

Since this was an open meeting, and invitations were sent to both Labor Union representatives and Labor Relations representatives; there were a number of pertinent questions asked. Professor Reynard, drawing on his store of knowledge and tact, seemed to answer them to the satisfaction of all concerned.

At this meeting, the Nominating Committee submitted its slate of officer nominees for the coming election. In addition, nominations were accepted from the floor.

In April, the Chapter had its annual social get-together. The program included a "Shrimp Boil" (probably unknown to you Yankees) and a dance. The members were urged to bring guests; and there was a good turnout. Everyone enjoyed the evening; and we strongly recommend to the other Chapters at least one social meeting a year. It will do a lot for drawing your group closer together.

BOSTON CHAPTER

Mr. Richard S. White, Industrial Consultant, addressed the Boston Chapter of the American Institute of Industrial Engineers on "The Economic Requirements for Automation" on Monday evening, April 23rd at the Smith House, Cambridge. Mr. White was originally scheduled to speak at the March meeting which was postponed because of a snowstorm.

"What are the economic ground rules for automation," "Can it pay for itself," and "Where are the likely applications in your plant" are a few of the questions Mr. White attempted to answer in his talk.

Mr. White is President of Automation Engineering Laboratory, Inc., Greenwich, Connecticut. He is a graduate of MIT and has been employed by Kurt Salmon Associates, Washington, D. C. as a staff engineer. Mr. White has also been with the Bankers Trust Company of New York, where he was the administrative assistant to the vice-president in charge of the Public Utilities Division.

CLEVELAND CHAPTER

The regular meeting of the Cleveland Chapter was held on April 5 at the Hotel Cleveland. Professor V. Donald Schoeller spoke on "The Need for Management Coordination in Material Handling Decisions". Professor Schoeller is the Associate Director of Management Development at the Case Institute of Technology, and was formerly Director of the Taylor Management Laboratory and the Annual Wharton School of Commerce Refresher Conference. He was a speaker at the 1951 International Conference for Scientific Management in Brussels and has conducted "Top Management" conferences in six countries. He has written several books and articles dealing with cost reduction techniques; he is a member of the American Arbitration Association; and he is a consultant to many large industrial firms and the United States Government. This meeting was designed to help solve some of the present day problems in material handling, and Professor Schoeller gave an excellent presentation.

DAYTON CHAPTER

The regular monthly meeting of the Dayton Chapter was held on April 9 in the Standard Register Company Auditorium. Mr. Edwin L. Slagle, President of AIIE, spoke on "The New Look in Wage Incentives". The meeting was informative and inspiring.

On May 8 the Dayton Chapter made a plant inspection trip to the Dayton Rubber Company. This was an excellent opportunity to observe the operations of an unusual (in this area) manufacturing plant. The main products that were observed being manufactured were tires, industrial "V" belts and printing rollers. The wives accompanied their husbands on this interesting trip.

FORT WAYNE CHAPTER

The Fort Wayne Chapter held their second Annual Conference on Thursday, April 26, at the Hotel Van Orman. A new record of 250 paid attendees and 32 exhibitors was established. Outstanding speakers were Mr. Brooks McCormick, Director of Manufacturing, International Harvester Company; Mr. J. F. Anderson, Manager of Production Engineering, Chrysler Corporation, Engine Division; Mr. Serge Birn, Management Consultant & President, The Serge A. Birn Company, Louisville; Mr. R. O. Ferguson, Consulting Engineer, Methods Engineering Council, Pittsburgh; and Mr. D. W. Karger, Chief Plant and Industrial Engineer, The Magnavox Company, Fort Wayne.

LOUISVILLE CHAPTER

Mr. Joseph Amann, National President of Engineers & Scientists of America, spoke at the March meeting on "Objectives and Activities of E.S.A." Mr. Amann discussed the situation encountered by the engineer in many of our large plants and of the engineer in general. Generally the engineer makes a good starting salary but the rate of increase over the years is slower than it should be. One of the objectives of E.S.A. is to increase this spread. Mr. Amann remarked that although there is a lot said and printed about the shortage of engineers, it has not been reflected in the income of experienced engineers.

The April meeting of the Louisville Chapter was held at the Kentucky Hotel on April 18th. Mr. John Farnbacher, Regional VEEP of AIIE, spoke on "AIIE National Policies, Objectives, and Activities."

Mr. Arthur Briese, nationally known humorist, was the speaker at the banquet held at the Brown Hotel on May 10th. This meeting was held jointly with all the other engineering and technical societies in Louisville, and was sponsored by the Louisville Chapter of AIIE. It was a big event for everyone.

On May 23 the Louisville Chapter made a tour of the Ford Plant which was very interesting. After dinner Mr. William Holohan, Production Manager of the Louisville Plant, gave an informative talk.

The new officers of the Louisville Chapter are: "Doc" Eldridge, President: Bob Craig, 1st Vice President; Bob McCormick, 2nd Vice President; Marv Garrett, Secretary; John Coleman, Treasurer; Jack Rouse, Horace Pearce, Ed Thoben, John Guenthner, Kenny Hendrick, Ed Vetter, Herb Rogers, Chas Vest, Board of Directors.

MILWAUKEE CHAPTER

Milwaukee Chapter is now about one year old. Membership growth continues at a rapid pace. All program presentations this year have been made by Chapter members. Recent programs have included papers on "Functions of an I.E. Department" by Marv Mundel, Vice Director, and Evan Scheele, Associate Director of Marquette U. Management Center; "Incentive Curves—The Rowan Plan" by Clarence Allen, Chief Industrial Engineer of Cudahy Bros. Co.; "Equipment Replacement Policy" by Joe Kutsch, Chief Industrial Engineer of the Falk Corp.; and "Evaluating the Performance of Industrial Engineers" by Glenn Wolfe, Chief Industrial Engineer of the Heil Co.

THE PENINSULA CHAPTER

The second annual Western Regional Conference of the AIIE, sponsored by the San Francisco-Oakland and Peninsula Chapters, was held on April 6 and 7 at the Mark Hopkins in San Francisco. The theme of the Conference was "Engineered Standards for Profits," and it was a great success. Attendance totaled 150, including many from Los Angeles, San Diego, Denver, Seattle, and many points. Facilities arrangements at the Mark Hopkins were excellent. The exhibits were well handled and drew a good crowd. The program was consistently interesting, and all comment was very favorable. The conference grossed $4700 and netted $1100. Half the proceeds go to National and one-fourth to each of the sponsoring Chapters.

The annual Western Regional Convention of the AIIE was held on April 7 at 3:30 P.M. immediately following the Conference. Thirteen delegates attended, representing the Los Angeles, Peninsula, San Diego, and SF-Oak Chapters. Annual chapter reports were summarized, and Grant Ireson reported for the Region. Membership growth for the Region was 37% last year. Two new Chapters were formed, at Salt Lake City and at Albuquerque, making 9 chapters in the area.

The regular monthly meeting of the Peninsula Chapter was held on April 10 at Crothers Memorial Hall, Stanford University. Mr. George R. West, Design Engineer for Color Television, Inc., San Carlos, California, spoke on "Automatic Quality Control". During the past two years, Mr. West has been a design engineer with CTI, working exclusively on the development and applications of automatic test equipment. He discussed the general requirements for automatic component and circuit testing equipment, and described and demonstrated an automatic testing device of considerable versatility.

The results of the annual election were announced at the April meeting. The new officers are: Al Colburn, President; Dick Houk, Vice President; Max Shaffer, Secretary; Don Grider, Treasurer; Lee Conton, Carl Kaiser, Sherman Lee, Directors.

The regular monthly meeting and the installation of officers of the Peninsula Chapter was held on May 8 at Mariani's Restaurant. It was a dinner meeting, and the ladies were invited. Mr. George E. Keck, Assistant to the Vice President, Engineering and Maintenance, United Air Lines, spoke on "The Industrial Engineer as a Professional Man". It was an enjoyable and informative evening.

ROCHESTER CHAPTER

The Rochester Chapter sponsored a conference which was held on Saturday, April 14, 1956. The conference was billed as "The New Look in Industrial Engineering." It was the intention of the conference to stimulate Industrial Engineers to keep abreast of the many newer techniques of a mathematical and statistical nature which are coming to the fore. In order to stress the point that the practicing Industrial Engineer can use and is using newer techniques, the program was put on by local Industrial Engineers. In most cases, each technique which was discussed was accompanied by an actual example of local application. The subjects ranged from basic statistics in measurement problems through Linear Programming, Queueing Theory, Matrix Algebra and concluded with a brief look at Games Theory and Minimax.

The luncheon speaker was Professor Andrew Schultz of Cornell, who also fills the post of Director of Research for AIIE. Professor Schultz spoke on "Keeping Pace with Industrial Engineering." This subject was in direct relation to the conference theme and outlined the problem facing the Industrial Engineer in his changing technology.

About 175 engineers from Rochester and the Western New York area attended, and despite the good Saturday weather, nearly everyone stayed until the 4:30 closing.

SAN FRANCISCO-OAKLAND CHAPTER

In April our national president of the AIIE, Edwin L. Slagle, Jr., gave the San Francisco-Oakland Chapter a very informative talk on the operation and organization of the National Chapter of the AIIE. In addition to the information which was contained in his message of the same title appearing in the November-December issue of the Journal, he told of some very interesting and somewhat startling things. Among them is the fact that the National President's job has demanded almost a full time schedule. Another is the very generous nature in which his employer, the Columbia-Geneva Steel Division of U.S. Steel Corporation, has contributed, monetarily, to support Ed in his travels, phone calls, and miscellaneous activities with the AIIE. His phone bill, alone, would surpass the salary of almost anyone attending the meeting. He has kept two secretaries busy almost full time on AIIE correspondence. These are a few of the reasons why Ed believes that it may be difficult to obtain national presidents in the future.

Ed also pointed out the personal sacrifices made by the personnel at the national headquarters. Over the past year a tremendous amount of overtime has been worked and people have performed way beyond the call of duty. In some cases national officers have had to pay their own expenses while on AIIE business. He hopes that our financial position will eventually be such that these individuals will not feel that it is an imposition to ask for funds with which to conduct AIIE business when they feel that their own budget cannot afford it.

On the brighter side, he feels that there is a wonderful future for AIIE. In numbers, the industrial engineers are gaining so fast that they may now be in third place and the AIIE has taken the lead in rate of growth.

Wives were invited to the dinner meeting in May, held at the beautiful Hotel Claremont, high in the Berkeley hills overlooking the San Francisco Bay and the Golden Gate. A. B. Casad, Chapter president, gave a short review of the chapter's many accomplishments during his year in office. This was followed by the presentation of prizes to members of the University of California student chapter for the best essays on industrial engineering subjects.

Installation of officers and directors was next on the program with the following individuals taking office: Robert L. Knighton, president; James L. Buckwalter, vice-president; John G. Ochsner, treasurer; W. A. Hecht, secretary; Thomas S. Lashbrook and Paul G. Dunmire, directors.

The program was highlighted with two moving pictures in technicolor. The first "Harvest of Commerce" by General Foods Corporation showed the harvesting and processing of food. The second movie showed the tremendous industrial and commercial growth which is taking place in California. It was presented by the Pacific Gas and Electric Company.

The chapter has been rounding out its program with a number of field trips. On April 27, the Friden Calculating Machine Company was toured. In February members of the chapter took a tour through the General Foods Plant in San Leandro, California.

(continued on Page 188)

RECENT READABLES*

AUTOMATION

"Industrial Engineering Can Aid in Developing a Maintenance Program," Napoleon Perkowski, *Automation*, pg. 28, February, 1956.

The author points out that the importance of the maintenance function increases in direct proportion to the degree of automation. It is his opinion that successful control of this function in an automated plant can be advanced if management recognizes that maintenance is a complex problem for which no quick or simple solution exists; and the successful techniques used in production offer an excellent guide to the methodology of controlling maintenance. The material in this article stems in part from research into the effect of automation upon the maintenance function, which the author performed in preparing his master's thesis.

"How Much Can Industry Automate?", Editors, *Factory Management and Maintenance*, pg. 124, March, 1956.

This report summarizes a recent American Society of Tool Engineers' survey of "What's ahead in automation." The prediction that about 16% of all manufacturing operations are automatable is based on a study covering major metal-working industries. The extent to which respondents estimate the individual operations of machining, metal forming, production welding, grinding finishing, materials handling, and inspection operations can be automated is given with a discussion of each.

"Electrical Computer for Pipeline Design Calculations," H. E. Thomas, *The Oil and Gas Journal*, pg. 136, March 26, 1956.

"Electronic computers lend themselves to pipeline design by eliminating many tedious and repetitious manual calculations." This article explains how the design computing time for a gas-transmission line has been reduced from two weeks to ten minutes after the initial programming of the computer. The step-by-step procedure followed to program the computer is illustrated.

"Computers Rescue Maintenance Men," *Plant Engineering*, pg. 92, April, 1956.

This article discusses how Los Angeles' Northrop Aircraft, Inc. is using computers to take over maintenance paperwork. For every machine, tool, and gadget, Northrop's Data Processing Section stores certain information on punch cards. From these cards computers can compile the information necessary for: 1) a preventive maintenance file, 2) the annual inventory of equipment, 3) the equipment catalog, 4) scheduling tests for duplicate machines, and 5) prediction of machine replacement. Because these reports are compiled in a matter of hours instead of days, Northrop believes statistical automation relieves maintenance to do things it is logically supposed to do.

"Digital Automation," M. L. Klein, F. K. Williams, H. C. Morgan, *Instruments and Automation*, pg. 2109, December, 1955.

The third article in a series on Digital Automation. The authors point out that the basic logical network is the Diode Matrix which can examine any given number of programmed premises and make any number of desired decisions. This article is an introduction to this basic digital technique.

"Digital Automation," M. L. Klein, F. K. Williams, H. C. Morgan, *Instruments and Automation*, pg. 74, January, 1956.

This is the fourth in the series of articles on digital automation by the authors. It is an introduction to the new and basic technique of linear programming. This new technique is finding applications in many unrelated fields—especially where complex possibilities in logistics are concerned because of its adaptability to digital computers.

"Basic Circuits Used in Digital Automation," M. L. Klein, F. K. Williams, H. C. Morgan, *Instruments and Automation*, pg. 271, February, 1956.

The basic circuits used in digital automation along with the diode and glow-tube coupling for 2-state signals are described. This technical description covers the amplifier, cathode follower, oscillator, free-running multivibrator, flip-flop, univibrator, blocking oscillator, phantastron, gating circuits, squaring circuit, clamp and scaling circuit. The article, the fifth in a series, is 9 pages and includes 28 illustrations.

"Multiplexing," M. L. Klein, F. K. Williams, H. C. Morgan, *Instrumentation and Automation*, pg. 470, March, 1956.

The sixth in a series of articles on digital automation by the authors. They point out that multiplexing is often the solution to the problem of handling many channels of data. This article gives the fundamentals of fixed-time and demand multiplexing, both electromechanical and electronic. The principles are illustrated in the design of typical multiplexers of both types.

"Digital-To-Analog Conversion," M. L. Klein, F. K. Williams, H. C. Morgan, *Instruments and Automation*, pg. 695, April, 1956.

This is the seventh in a series of articles by the authors on digital automation. It is explained that weighting is the technique used to convert digital signals into analog form. A mechanical and an electronic digital-to-analog converter are described, plus a complete multiplexed digital system with analog input and analog output.

COST CONTROL

"A Ten-Point Cost Reduction Program," Editors, *Factory Management and Maintenance*, pg. 92, February, 1956.

This article announces a series of ten articles which are designed to give the success story of a three-year cost-cutting drive by the Mueller Brass Company, Port Huron, Michigan.

"Maintenance Control by the Clock Provides Yardstick for Measuring Costs," J. G. Armstead and J. R. Beerle, *Plant Engineering*, pg. 86, March, 1956.

The authors discuss a system of measuring maintenance costs known as an "Earned Hour Control Plan." This plan is essentially one of analyzing past performance and establishing standards based on average hours per job or on supervisor's estimates. The authors point out its advantages as: 1) minimum system installation time, 2) saving of high cost of collecting standard data, 3) can be initiated and operated by a minimum staff, and 4) a realistic and flexible measure of performance.

* The Editor wishes to acknowledge the invaluable assistance of Mr. Lewis Phillips of the Ethyl Corporation, Baton Rouge, Louisiana, who prepared the listing in this issue during the absence of the Editor.

"Newest Way to Avoid Downtime," D. H. Denholm, *Factory Management and Maintenance*, pg. 88, April, 1956.

This article shows how the Chase Bag Company initiated and administers an incentive plan for machine tenders. This program gives the tender an incentive to "keep 'em rolling". It is a concept that may grow in importance with the march of mechanization.

"Selling The Workforce on Cost Control." *The Communicator* (Employers Labor Relations Information Committee, Inc., New York 17, N. Y.), pg. 2: 8, No. 2, 1955.

This report discusses the benefits realized by the Johns-Manville Corporation's "Worker Smarter" program which was initated in 1954. The program is built around more effective communications channels and better understanding by *all* employees on the tie-in between competition, production, efficiency and job security. This is accomplished by informal foreman-employee meetings on company time.

"Seven Smart Moves to Cut Costs," Editors, *Factory Management and Maintenance*, pg. 76, April, 1956.

This article shows seven results of the Lamson & Session Company's work-improvement training program. It includes an explanation of how the program was initiated and the philosophy behind it.

FORMS CONTROL

"Forms—Their Design, Control, Usage," George Bick, *Office Management*, pg. 24, February, 1956.

Part one of a series of articles. The author points out that forms, the communication links of the office, are the largest item in office overhead. He discusses some of the rules of form control and tells of the benefits of preparing your own forms.

"Mechanized Maintenance Control," William J. Collier, *Factory Management and Maintenance*, pg. 118, March, 1956.

This 6-page report summarizes how the Tapco Division of Thompson Products, Inc., automated maintenance control with accounting machines. The author points out how 12 people with business machines do more paperwork—faster and better—than 300 clerks could. Ten functions which this set-up performs are discussed along with the control they provide.

"Mechanical Paperwork for Preventive Maintenance," William H. Kearns, *Factory Management and Maintenance*, pg. 142, February, 1956.

This article shows how Lockheed-Marietta reduced the clerical costs of their preventive maintenance program by mechanization. One maintenance planner and two clerks now perform all the functions of scheduling, issuing work orders, following up work orders, checking performance, assembling costs, and analyzing results. The author explains how the program was initiated and operates.

"Reducing The Burden of Office Forms," Alven S. Ghertner, *American Business*, pg. 30: 3, September, 1955.

This short article gives some tips on how to control forms. It includes a discussion of 10 basic principles of form control and design.

"The Paper Chase," Leslie H. Matthies, *The Office*, pg. 76, April, 1956.

This article shows that a paper chase, to cut down copies arbitrarily, is rarely an answer to administrative overhead. The author points out that this often denies supervision information important to their function and results in an increase of overhead on a departmental basis because of typing which it necessitates.

GENERAL

"*Atoms For Peace—The Geneva Atomic Papers*, A Whaley Eaton Service, Munsey Building, Washington 4, D.C.

This catalog lists over 1,000 scientific and technical papers presented at the UN Conference (Geneva) on Peaceful Uses of Atomic Energy. Indexed by subject, country, and number of pages, is a quarter of a century accumulation of scientific and technical data. Many of the papers contain extensive formulas, charts, graphs, tables, bibliographies, symbols, and photographs. Basic price per page for reproductions listed is 17¢. Special rates can be quoted for orders in excess of 300 pages.

"How The Army Controls Maintenance," R. L. Marinello & Keith R. Barney, *Plant Engineering*, pg. 109, April, 1956.

This article describes the system developed by the U. S. Army to maintain and economically operate its huge plant since World War II. It shows how the program has been developed around the basic tool-cost budget. Several examples of savings attained are cited.

"Job Enlargement Is Worth Checking," G. J. McManus, *The Iron Age*, pg. 51, February 23, 1956.

A special report on a new concept of work assignment known as job enlargement. The author says "It can mean big money savings, better job efficiency, and widened employee interests" . . . by giving a worker a greater variety of work and more responsibility. The report is based on a study of two companies, IBM and Detroit Edison, who are working with this new concept and shows the limits as well as the benefits.

"Location Analysis," James K. Blake & Alfred G. Larke, *Dun's Review and Modern Industry*, p. 29, April, 1956.

This article is a six-part special emphasis study. It includes reports on the right and wrong ways to evaluate business and industrial locations; a checklist of the important points to be considered in comparing the advantages of different localities; a suggested list of sources that can provide much of the detailed data necessary for wise decision-making; and case studies of how companies are using many of the best tools of location analysis.

"Longren's Production Team—How It Raises Plant Efficiency," Bud Pasnow, Bob Cole, and John Podgurski, *Plant Engineering*, pg. 105, March, 1956.

This article points out how the plant engineer, industrial engineer, and maintenance foreman work together to slash production time at the Torrance, California, plant of the Longren Aircraft Company. An example is cited where the assembly time for an aircraft wing pod was more than halved and maintenance time reduced 24 hours per week through the efforts of the production team.

"Productivity Trends—II Portents For the Future," Milton Lipton, *Business Record*, pg. 148, April, 1956.

This article, the second of a three-part series dealing with productivity in American industry, looks ahead to the economy of the future. Potential economic growth is viewed from the perspective of related trends in out-put per man-hour, business investment, and spending-saving relationships. An article in the February *Business Record* traced the influence of labor and capital inputs on the historical trend of national output. A succeeding article will discuss diversities among productivity trends.

MATERIALS HANDLING

"New Split-Level Warehouse," Editors, *Modern Materials Handling*, pg. 84, March, 1956.

The Jordan Marsh Company hopes to retain the advantages of single story handling while achieving the space economies of a multi-story building in its new warehouse. Ramps connect five levels in the structure which contain 507,000 square feet of storage space. The ramps eliminate the need for eleva-

tors and the delays associated with usual methods of vertical travel.

"Pallet Loaders Pace the Plant," Editors, *Modern Materials Handling*, page 86, March, 1956.

Dow Brewery Ltd. of Montreal needed equipment that could handle fast & frequent changes in pallet patterns. Accordingly, they installed two semi-automatic pallet loaders capable of handling up to 1350 units/hour. These machines require little more space than a manual stacking area, are of open construction which benefits maintenance, and require one operator each.

"Containerization—Our Newest Handling Principle," Editors, *Modern Materials Handling*, page 119, April, 1956.

A 16-page report which describes the latest developments in its field. This special report covers many aspects of container development, from standard types to new models, from limitations to latest uses. The author discusses the cost, construction, current status, and advantages of such units as large metal shipping containers; removable vans; aircraft pods; pails, drums, and carboys; wire mesh models; crates and boxes; fiberboard cartons; and plastic and rubber drums.

"Special Device Cars—A Growing Trend," Editors, *Modern Materials Handling*, pg. 110 April, 1956.

Last year's changes in tariff provisions, permitting the free return of shipper-owned racks and containers, gave impetus to an already growing trend in the use of special device cars. With the aid of illustrations this short article describes equipment for reducing damage and cutting car-loading time.

"Eliminate Packaging Guesswork," Willard S. Mielziner, *Modern Materials Handling*, pg. 114, April, 1956.

"Lack of specific information on the degree and nature of impact has hampered the package engineer in developing the lowest cost yet most effective protection for his product." In this article the author explains where to use impact recorders to aid in obtaining the best possible package design.

"Conveyorization at Appliance Park," Editors, *Modern Materials Handling*, pg. 89, March, 1956.

The most noteworthy features of the materials handling system at the General Electric Company's newest and largest mass-production plant at Louisville, Kentucky, together with the principles on which they are based, are described in this special 18-page report. The facilities at Appliance Park provide over 4 million square feet of manufacturing and warehouse space planned to take full advantage of the latest and most modern methods of production and materials handling. More than 45 miles of conveying equipment are currently in operation in the division. Solutions to the problem of delivering hundreds of different parts in large quantities to multiple assembly lines in the Household Refrigerator Department is pictorially illustrated. A package-handling system for delivering completed refrigerators to the Warehouse from the final assembly conveyors and sorting them automatically at that point is also described.

"What Is an Integrated Materials Handling Program," George G. Raymond, Jr., *Advanced Management*, pg. 6, April, 1956.

The author, president of the Materials Handling Institute, classifies the benefits to be derived from an intensive and integrated materials handling program into five parts: 1) Increased Machine Utilization Efficiency, 2) Reduced Fatigue, 3) Safer Handling, 4) More Effective Use of Storage Space, and 5) Production Pace Set By Handling Space. The Article considers the objectives, physical layout, and types of equipment for such a program.

"Making the Building Efficient," I. M. Footlik, *Modern Materials Handling*, pg. 107, March, 1956.

Planning a new plant with handling operations in mind will save money—and many headaches as well. The author details some of the factors to consider and some of the pitfalls to avoid. He discusses building shape, ceiling height, floor-to-roof clearance, column spacings, floor load capacities, doorway heights and widths, service areas, truck docks, and elevators.

METHODS

"Improving Office Methods: A Six-Point Program," John R. Crowley, *The Management Review*, pg. 814, November, 1955.

This article summarizes an address given by the author before the National Office Management Association. In it he outlines six basic steps in an approach to methods improvement. Included are references for further information on such a program.

OPERATIONS RESEARCH

"Operations Research—Top Management Tool," E. O. Boshell, *Dun's Review and Modern Industry*, pg. 49, March, 1956.

This article is a study of how the Westinghouse Air Brake Company made operations research a proficient part of its organization. The author follows the growth of OR in his company and gives the present functions of the OR Director. He also includes two examples of the application of Operations Research and the results.

"Practical Linear Programming Applications," Harry T. Schwan, *Industrial Quality Control*, pg. 4, March, 1956.

In this article the author discusses how linear programming assists management and areas where it has been applied with success. A comparison of solutions by logic and linear programming; for an example a problem involving distribution costs is given. However, the step by step linear programming calculations are not shown. As pointed out by the author, linear programming is a tool which can be used to gain insight into the complications surrounding each decision.

"Teaming Computers And Operations Research," Morley G. Melden, *Factory Management and Maintenance*, pg. 68, April, 1956.

A case study of a tough shipping-distribution problem of General Foods and how it pays off. This article gives a thumbnail sketch of the solving of the problem from its beginning to end. It includes a description of the General Food's OR team.

"The Use of Linear Programming To Improve The Quality of Decisions," A. C. Rosander, *Industrial Quality Control*, pg. 11, March, 1956.

In this article the author discusses ways of improving decisions, areas of application for linear programming, and what linear programming is. In layman's language he solves a travel problem, a tax problem, and an automobile production problem graphically, and a shipping problem mathematically.

"What Is Operations Research," Annesta R. Gardner, *Dun's Review And Modern Industry*, pg. 46, December, 1955.

The material for this article was gained from a survey of Operations Research leaders throughout the country. It contains definitions of OR by 19 of these leaders and their ideas on its applications—proven and possible. The author discusses OR's place in company organization.

PRODUCTION CONTROL

"Production Control Cuts Schedule Losses," Ernest Schleusener, *Factory Management And Maintenance*, pg. 134, March, 1956.

This is the first in a series of ten articles on cost reduction out of the experience of the Mueller Brass Company. The author

points out one of the success secrets as fact-filled reports plus a new twist in linear programming. The material is presented under the sub-headings of Keys To Program, Linear Programming, and Shipping On Time.

QUALITY CONTROL

"Now Better Quality—Plus $200,000," Ernest Schleusener, *Factory Management and Maintenance*, pg. 98, April, 1956.

This savings for the Mueller Brass Company comes from less scrap, less rework, and lower-cost inspection. The author explains how statistical quality control was initiated in his company to obtain these savings. He points out nine steps in instigating a "Quality Awareness Program" and potential areas of application of quality control.

"New Uses For Quality Control," *Staff Report: Operations*, Research Institute of America, 589 Fifth Ave., New York 17, N. Y., 1955.

This article discusses the following new applications of quality control and how they can cut costs: 1) Keeping Control Over Operators, 2) Controlling Intangibles Like Taste or Color, 3) Is 100 Percent Inspection Necessary?, and 4) Reducing Inspection Costs.

"Quality in Six Lessons," Editor, *Factory Management and Maintenance*, pg. 113, February, 1956.

This short article explains how Westinghouse was able to reduce rejects by 50% in one of its plants. It tells how this reduction was accomplished with a training plan that brought the workers into the act and showed to them the why as well as the how of quality.

WORK MEASUREMENT

"Setting Time Standards on Maintenance Work," James G. Bralla, *Advanced Management*, pg. 20, April 1956.

The purpose of this paper is to illustrate special techniques involved in using MTM and other advanced means of work measurement to obtain practical standards for maintenance. The author discusses the use of both time study and predetermined times on any one standard or formula. He points out that the potential savings from the application of time standards to maintenance operations is perhaps greater than on other operations because of maintenance supervision and control difficulties.

BOOKS

1955 Collected Technical Papers. (American Society of Tool Engineers), Collected Papers, American Society of Tool Engineers, 10700 Puritan Avenue, Detroit 38, Michigan, 347 pages, $5.

This leatherette bound volume contains all the papers and panel discussions presented at the 23rd annual conference of ASTM in Los Angeles. Subjects discussed include use of magnesium for low-cost tooling, coding and classification systems, cold steel extrusion tooling, ceramic parts and tooling for mechanical applications, and the setting of automation goals. The four panel discussions covered: 1) Plastic Tooling For Production, 2) Preparing Engineers for Manufacturing Responsibilities, 3) Coordination of Manufacturing Management, and 4) Quality Control Through Realistic Tolerances.

Electronic Computers And Management Control, George Kozmetsky and Paul Kircher, McGraw-Hill Book Co., 330 West 42nd St., New York 36, N.Y., 304 pages, $5.

This book is designed to tell operating men how and where electronic computers can help solve management problems, "without wading through a lot of complex, supertechnical gobbledygook." It explains how computers work, describes each type and its major components, and gives examples of everyday applications. The authors point out how to select an electronic data processing system for your plant.

Foundations of Productivity Analysis, Bela Gold, Univ. of Pittsburg Press, Pittsburg, Pa., 1955, 303 pages, $5.

The author discusses methods for the analysis and control by management of changes in industrial productivity. The five parts of the study cover objectives and methods of analyzing productivity; factors involved in adjustments in productivity; the effects of various forms of productivity adjustments; and cost and other objectives as guides for management in the formulation of policy in regard to productivity adjustments.

Job Evaluation, E. Lanham, McGraw-Hill Book Co., 330 West 42nd St., New York 36, N.Y., 404 pages, $6.

The author explains the steps that must be performed in installing and maintaining a job-evaluation program, how these steps should be carried out, and who should be responsible for doing so. He outlines the desirable current techniques and discusses the philosophy behind each. The book includes a chapter on the role of organized labor in job evaluation.

Industrial Society, Georges Friedmann, The Free Press, Glencoe, Ill., 436 pages, $6.

A scholarly treatise on the impact of scientific management of the industrial worker subtitled "The Emergence of the Human Problems of Automation." It summarizes many psychological, physiological, and sociological studies made to discover how to make the transition to routine, repetitive tasks less troublesome. It offers much evidence on how to make the new transition to automation for which many companies are now preparing. The book considers in detail such factors as the physical layout of the plant, work rhythm, fatigue and monotony, retraining, and others.

Measuring Business Changes, Richard M. Snyder, John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y., 382 pages, $7.95.

This book contains explanations of over 50 key indicators that can be used to interpret and forecast changing conditions that affect the business world. The nature and significance of each indicator is discussed by the author, along with its uses and possible misuses. These indicators are grouped under nine major heads: National Income and Product, Population, Labor Employment and Earnings, Commodity Prices, Production and Business Activity, and Stock Prices.

The NOMA Bibliography For Office Management, National Office Management Association, 132 West Chelten Ave., Philadelphia 44, Pa., 48 pages, $5.

This booklet is an annotated listing of hundreds of books, articles, booklets, and other material which have been published on office management during the past five years. All aspects of office management from absenteeism to work simplification are included.

Planning The Future Strategy of Your Business, Edited by Edward C. Bursk and Dan H. Fenn, Jr., McGraw-Hill Book Co., Inc., 330 West 42nd St., New York 36, N.Y., 308 pages, $4.25.

The question "How are many companies, both medium-sized and giant, planning their strategy to meet the many changes the future is bringing?" was the theme of the recent twenty-fifth annual National Business Conference of the Harvard Graduate School of Business Administration. This book contains the testimony of over two dozen business leaders and thinkers on the practical plans already being used. Included in their discussions are automation, the guaranteed annual wage, operations research, and the "task force" concept of management.

Practical Plant Layout, Richard Muther, McGraw-Hill Book Co., Inc., New York 36, N.Y., 363 pages, $12.

The basis of this volume is the principles and techniques of plant layout which have evolved from the conversion and

reconversion of plants to wartime and back to peacetime production. The book is divided into the four major sections of Nature of Plant Layout, Factors Influencing Layout, Planning Layout, and Suggestions for Management. The author, a former professor of industrial production at MIT, analyzes eight factors which influence layout: 1) Men, 2) Machinery, 3) Materials, 4) Movement, 5) Waiting, 6) Services 7) Plant, and 8) Changes. He uses many sketches, photographs, flow charts, and tables to make his points clear to the reader.

Proceedings of Symposium on Automation, Engineering Publishers, GPO Box 1151, New York 1, N. Y., 114 pages, $5.

This report is a record of the papers given at the September, 1955, symposium of the Radio-Electronics-Television Manufacturers Association. Contents are grouped under five sections: 1) Mechanization For High Volume Assembly, 2) Data Sensing, Processing, and Utilization, 3) The Future of Automation, 4) Automation for Low-Volume Production, and 5) Redesign For Automation of Components and Products.

Profit Sharing for Small Business, J. J. Jehring, Profit Sharing Research Foundation, 1718 Sherman, Evanston, Ill., 53 pages, $1.

This study is based on information gathered from 78 small businesses that have been practicing various forms of profit sharing for a number of years. It describes the benefits and includes specific data and operating ratios for many successful plans; and a check list for designing a deferred profit-sharing trust plan. It gives specific information that will help answer many of your questions.

Successful Production Planning and Control, American Management Association, 1515 Broadway, New York 36, N.Y., 202 pages, cloth bound, $5.50.

Much of the information presented in this report had been prepared by executives from industry, engineers, and consultants, for a conference on production planning and control held in New York in 1955. Subjects treated in this book include budgetary responsibility, effective inventory management, quality control as an aid to production, and use of incentives. The functions of the purchasing group, traffic department, production (industrial) engineer, and product manager as related to this program are also discussed.

Work Sampling, Ralph M. Barnes, Wm. C. Brown Company, 215 West Ninth St., Dubuque, Iowa, 265 pages, $5.75.

The author's abstract is as follows:

"This volume explains how sampling may be used for measuring work as well as for measuring delays of men and machines. The basic concepts are presented. . . cases and specific applications are included as illustrations.

There is also a report of research in work sampling conducted by Ralph M. Barnes at the University of California, as well as reports of research in this field conducted by others."

Electronic Data Processing for Business and Industry, Richard G. Canning, John Wiley & Sons, Inc., 440 Fourth Avenue, New York 16, New York, 332 pages, illus. 6 by 9¼, cloth, $7.00. Textbook edition also available for use in schools and colleges.

Presents in the language of management the principles of selecting and using new electronic clerical systems for greater business efficiency. Contents:—Electronic Data Processing: A New Management Tool. Patterns of Data Processing. Summary of Electronic Data Processing Machines. Programming Typical Clerical Operations. The Systems Study. The Electronic System: Initial Design. The Electronic System: Detailed Design. The Role of Operations Research. Equipment Characteristics. Management's Program for Obtaining a Reliable System. Appendix 1: Overcoming Barriers to the Acceptance of New Ideas and Methods, by Robert Tannenbaum. Appendix 2: Casting out Nines. Bibliography and References.

Industrial Wage and Salary Control, Robert W. Gilmour, John Wiley & Sons, Inc., 440 Fourth Avenue, New York 16, New York, 261 pages, 53 illus., 6 by 9¼, cloth, $7.50.

A practical presentation of the development, installation, and administration of point evaluation plans as the basis for sound wage and salary programs. Emphasizes, through graphic illustrations and by actual examples, the importance of applying statistical techniques to job analysis and evaluation so as to provide equitable payment plans and improved expense controls.

Engineering in History, Kirby, Withington, Darling, Kilgour, McGraw-Hill Book Company, 530 pages, 6 by 9, illus., $8.50.

The history of engineering from 6000 B.C. to the present, written by a unique combination of authors including both engineers and historians. The book shows how various factors in the physical and cultural environment conditioned engineering advance, and conversely how engineering has affected other human activities including health, material welfare, and even life itself. Emphasis is placed upon the history of civil, electrical, and some aspects of metallurgical (iron and steel) and mechanical (power and transportation) engineering. Contents: Origins. Urban Society. Greek Engineering. Imperial Civilization. The Revolution in Power. Foundations for Industry. The Industrial Revolution. Roads, Canals, Bridges. Steam Vessels and Locomotives. Iron and Steel. Electrical Engineering. Modern Transportation. Sanitary and Hydraulic Engineering. Construction. Reflections. Index.

Design for Decision, By Irwin D. J. Bross, The MacMillan Company, 1953, 275 pages, $4.75.

The author has accomplished a difficult task—a successful, non-mathematical prose explanation of statistical concepts and methods. Sampling, probability and statistical decision are explained in terms which are easily understandable.

Industrial Psychology and Its Social Foundations, Milton L. Blum, Revised Edition, Harper and Brothers, New York, 1956, 612 pages, $6.00.

A complete revision of the author's earlier book, presenting current material in the areas of Industrial Psychology, such as Motivation and Work, Measuring Attitudes, Job Satisfaction, Leadership, Fatigue, Human Engineering, etc.

Human Relations in the Industrial Southeast, Glenn Gilman, The University of North Carolina Press, Chapel Hill, 1956, 327 pages, $5.00.

This study of personnel history and practices in southern textiles, stressing the emergence and growth of the mills as regional institutions, clearly shows the distinguishing features of the industry. The impact of local, regional, and national influences on the developing pattern of human relations in the industry is traced from its origin to the present day, in order that the peculiar problems of this geographic and industrial area may be understood.

Proceedings of The Institute on Operations Research for Business and Industry, University of California, Los Angeles, 1956, 63 pages, $5.00.

Proceedings of an Operations Research Institute, sponsored by UCLA, April 28 and 29. The purpose of the Institute was to introduce the philosophy, methods, and application of operations research to management level personnel in California. Included are papers presented by M. L. Hurni, Andrew Vazsonyi, Gifford H. Symonds, Dean E. Wooldridge, Russell L. Ackoff, Roger R. Crane and William R. Fair.

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